NUTRITION
AND
CLIMATIC STRESS

With Particular Reference to Man

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to

Robert Hanson Mitchell

FIRST LIEUTENANT U S A F

May his sacrifice not have been in vain

PREFACE

The material contained in this monograph was prepared originally under a contract between the University of Illinois and the Quartermaster Food and Container Institute for the Armed Forces, Chicago, Illinois The subject is of importance to the proper rationing of Army personnel in different climates and at different altitudes, and most of the experimental and observational investigations dealing with it during the period of the late war were motivated by such considerations However, the relationships between nutrition and climatic stress are much broader than this in their applications to the problems of practical nutrition and in their bearing on the principles of the science of nutrition Hence, it was decided to publish the report of the study for general distribution The authors express their appreciation to Mr George Gelman, Technical Director of the Institute for releasing the report for this purpose

The original report was submitted to the Institute in July of 1948 and represented literature coverage up to about April 1, 1948 This report has been thoroughly revised up to about October 1, 1949, in preparing the present monograph, although the authors realize that, because of the many and diverse avenues of publication for material of this nature, all of the available information may not have been consulted

In reviewing the mass of pertinent literature and unpublished material the authors have had two purposes in mind first, to cover thoroughly and critically those experiments and observations dealing directly with the relationships of nutrition and climatic stress, namely, the effect of climatic stress on nutritional requirements, and the effect of the food supply upon tolerance to climatic stress, and, second, to discuss the background information, bearing indirectly, and perhaps only remotely, upon the nutrition-environmental stress theme The latter purpose will, it is

hoped, aid in an appreciation of the larger problem of the impact of climate upon animal physiology, and will, it is hoped, aid to some extent in explaining the nutritional impacts of climatic aggression The literature on the physiological effects of climatic factors, referred to in the monograph, has been selected from a much larger bibliography on the basis of pertinence to the main problem It has been discussed in as logical a fashion as the limitations of the authors in this broader area of knowledge would permit

The success of this undertaking, such as it is, would have been impossible without the assistance and counsel of many agencies and individuals Special acknowledgments should be made of the assistance of the following

Miss Susan Boyer and her associates in the Office of the Quartermaster General in Washington, D C, for permitting access to and assistance in using the index of pertinent research sponsored by George Washington University, including confidential and restricted, as well as published, material, Mr Martin P McDonough, technical librarian of the Quartermaster Food and Container Institute, for access to the index file of confidential and restricted material at the Chicago depot, Colonel Jack E Finks of the Research and Development Branch, Military Planning Division, Office of the Quartermaster General, for assistance in securing access to unpublished material in the Army Medical Library, the War Library in the Pentagon Building and the literature index of the Quartermaster General in Washington

Either one or both of the authors received valuable assistance and guidance in personal interviews with Dr Ancel Keys of the University of Minnesota, Dr D B Dill of the Army Chemical Center, Edgewood, Maryland, Drs R E Johnson and R M Kark of the Army Medical Nutrition Laboratory, Dr Paul E Siple, Research and Development Division, War Department General Staff, Captain A R Behnke, Naval Medical Research Center, Bethesda, Maryland, and Lieutenant James L D Roth, and Dr T W Robinson, Air Materiel Command, Wright Field, Dayton, Ohio

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Chapter I

INTRODUCTION

Man inhabits all climatic regions of the Earth, as diverse as those of the polar regions and the tropics. With the development of the airplane, he has extended to a considerable degree the third dimension of the habitable Earth with its own peculiar climatic features. These facts testify to the great adaptive powers of the human organism. These adaptive powers can be broken down into physiological and constitutional factors on the one hand, and cultural factors on the other.

By reason of purely physiological processes the human body can maintain its temperature within narrow limits under variable environmental conditions simply by modifying its rate of heat production, or by modifying the rate at which heat is dissipated from the surface of the body and from the respiratory tract. Constitutional differences between races of men, such as differences in body size and conformation, differences in pigmentation and other properties of the skin, and differences in the efficiency of temperature regulatory mechanisms may also operate in climatic adaptations.

By cultural methods man can modify his own immediate environment and thus minimize the stress of the climate in which he resides. The type and quality of clothing and of housing, and the use of artificial heating, and later cooling, devices enable him to supplement physiological processes and constitutional character-

istics in maintaining his normal body temperature in the face of extreme climatic stress

The diet of men living *in different climatic regions* varies greatly, both in quantity and in the nature of the foods of which it is composed These differences are dependent upon the availability of foods of different descriptions, obviously The prevalence in the diet of the Eskimo of foods high in protein and in fat may be largely due, as Thomas (1927) believes, to the unavailability of carbohydrate foods during most of the year On the other hand, Burton and associates (1940) have reported that, in a cool environment, human subjects prefer foods of higher caloric value per gram and lower equivalent respiratory quotient, both of which are prominent characteristics of fats, and that appetite plays a significant role in acclimatization to cold This belief derives a certain measure of circumstantial support from the fact that prevailing diets in hot climates are so often poor in fats and high in carbohydrates (Woodbury, 1942 Nicholls, 1938, Lindstedt, 1938) There is a possibility, therefore, that men to a certain ex*tent select their foods and acquire food habits best adapted to aid* them in combating climatic stress

These possible relationships between diet and tolerance to *climate have been studied sporadically and* largely upon laboratory animals, for many years However, during the period of World War II these relationships demanded specific and immediate investigation upon human subjects for the purpose of rationing our service men assigned to different climatic regions in the most effective way The value of protective clothing in polar and sub polar regions, or in high altitude flying, is limited, because, first the protection afforded against intense cold by any reasonable assemblage of clothing is a function of time, i e , each assemblage of clothing has its "tolerance time" (Newburgh and Harris, 1945) In the second place, an assemblage of clothing reasonably effective in extreme cold is so cumbersome as to impair the efficiency of a man in the performance of such manual operations as *the piloting or navigation of an airplane, or the* manipulation of a machine gun If certain dietary modifications would supplement clothing in protecting aviators or ground troops against cold, it may be advisable at certain times to modify army rations for use in cold climates or cold seasons

In the tropics another dietary problem arises from the possibility that the extreme sweating induced by the critical need of dissipating body heat at a rapid rate may lead to excessive losses of water soluble nutrients—vitamins, minerals and amino acids—necessitating greater supplies in the diet Temperature and humidity both contribute to the magnitude of these losses, such as they are

In high-altitude flying, the diminished atmospheric pressure, and in particular the low partial pressure of oxygen in the inspired air, is a type of climatic stress presenting a serious hazard to the preservation of physiological and psychological efficiency and even of life itself The maintenance of cabin pressure at ground-level magnitude with normal partial pressure of oxygen is a complete defense against this hazard except in combat or in accident The breathing of pure oxygen in an airplane cabin not so fortified is effective in combating the anoxic stress up to certain high altitudes But some supplementary protection such as may be afforded by diet would be of value in such critical situations as bail out, loss of cabin pressure or failure of the oxygen system when additional seconds of consciousness can mean the difference between life and death The proper rationing of mountain troops and mountain communities would be another phase of this problem

The urgency of these problems bearing on the relationship of diet to climatic stress induced government war agencies particularly the Office of Scientific Research and Development to spend many hundreds of thousands of dollars in aiding scientific research in universities and other institutions, directed toward the improvement of army and navy rations in varied climates This report will be concerned with the physiological studies of diet as related to climate In addition many biochemical and engineering investigations of food stability and preservation under different conditions of temperature and humidity, and of proper packaging and transportation, were undertaken under the stimulus of the war effort

Experimental air-conditioned chambers and decompression chambers have been used in most of the investigations to be reviewed in this report, whether the subjects were laboratory ani-

mals or men, but the simulation of climatic conditions in such equipment, and in particular the simulation of living conditions in different climates in restricted quarters, is never complete. The diurnal variations in temperature, humidity, air motion and insulation, both direct and indirect, are difficult or impossible to duplicate in an experimental chamber, hence, the necessity of checking laboratory results with actual field tests, before practical conclusions can be drawn. In these checks, questions of food habits of men and of the acceptability of proposed dietary measures are of the greatest importance.

The information secured from the many experimental explorations into this, until recently, largely unexplored area of diet in relation to climatic stress may be divided, first, into the various types of climatic stress characteristic of the arctic and antarctic regions, the tropics, and high altitude, and then into two distinct divisions, one dealing with the effect of climatic stress on dietary requirements, and the other dealing with the effect of diet on tolerance to climatic stress. The dietary modifications that will be considered under the latter heading will be modifications of an already adequate diet as this term is ordinarily used. Obviously, a diet inadequate in one or more nutrients can be improved for use in any climate by correcting its deficiencies.

The literature coverage bearing directly on the relationship of diet to climatic stress should be fairly complete and has been supplemented by access to unpublished reports of various research agencies concerned with this subject, especially during the period of the late war. The various sections of the report include also discussions of the physiological effects of the climatic factors considered. The literature citations here are admittedly incomplete and have been selected for special reasons from a much more complete file. Only those physiological responses to climatic stress have been considered that bear some relationship, direct or remote, to nutrient requirements or nutritional processes.

Nutrient requirements are commonly thought of as being functions of body size or of metabolic rates. The dependence of requirements for vitamin A or for carotene upon body weight has been clearly established by the classical work of Guilbert and his associates, and confirmed in many other laboratories on many

species of animals The usefulness of the concept of metabolic body size (such as $W^{.75}$) in assessing maintenance requirements for protein and for energy has been demonstrated, its application to maintenance requirements for calcium and for phosphorus seems justified The requirements for water and for iodine are proportional, under non stress conditions, to the heat production of the animal, while the need for those micro nutrients, both minerals and vitamins, entering into the structure of enzyme systems, or serving as enzyme activators seems to be proportional to the amount of work to be done by these catalysts, i e, the amount of organic nutrients consumed and metabolized

In what ways may these relationships be disturbed by the impact of climatic stress? The following possibilities are conceivable

(1) Climatic factors, particularly temperature may modify nutrient requirements by modifying the activity of the organs of digestion and assimilation or of the organs of excretion (gastro intestinal mucosa, kidneys, lungs, skin and sweat glands) through which nutritive material may be lost from the body

(2) Climatic factors particularly temperature, may disturb the heat balance of the body, leading to an elevation or a depression of deep tissue temperature, with a corresponding acceleration or deceleration in metabolic reactions involving both the assimilation of nutritive material and the destruction of metabolic agents

(3) Climatic factors may disturb endocrine functions and endocrine relationships For example the physiological responses to cold are mediated by the thyroid, pituitary and adrenal glands In accordance with the trace substance enzyme thesis of Green, the hormones produced by these glands may be considered either as potential enzymes or as prosthetic groups of enzymes A modification of their secretion brought about by climatic stress would conceivably change the course of metabolic reactions or their rates, and thus may modify nutrient requirements

(4) The motivation for mental and muscular work may be depressed or augmented by environmental stress In this way, the voluntary activities of the body and the corresponding nutrient requirements may change

(5) The efficiency of muscular work may conceivably be dis-

turbed at extreme temperatures or atmospheric pressures The food energy required per unit of work would change correspondingly

(6) The physical capacity for doing work, both mental and muscular, may be impaired by environmental factors, such as diminished atmospheric partial pressure of oxygen

(7) Environmental stress may alter the basal expenditures of energy and of the individual nutrients, either under strictly basal conditions, involving the control of environment, or under habitat conditions, or both

(8) Another response to climatic stress may be a change in the specific dynamic action of food, leading to a better or a poorer utilization of food energy

The above possibilities represent one aspect of the relation between nutrition and climate Another aspect is the effect of dietary modifications upon resistance to climatic stress, having in mind only those modifications within the area of balanced diets The correction of deficiencies in diets inadequate under non stress conditions would be expected to have favorable effects on resistance to any stress, it may be a proper subject for demonstration but hardly for experimental inquiry

Modifications of an adequate diet may conceivably modify resistance to climatic stress by (1) modifying heat production of the animal, (2) facilitating or retarding the dissipation of heat from the body through effects on the vasomotor system or on the composition of the peripheral tissues, (3) modifying the functioning of the nervous system and of the special sense organs, and neuromuscular coordination, (4) economizing on a limited oxygen supply by changes in the metabolic mixture so that more energy is liberated per unit of oxygen inspired, and probably in other ways

The possibility that different species of animals will react differently to climatic stress, either in kind or in degree, is a constant hazard, perhaps more so in this field than in most others, to the carry over of observations and conclusions from experimental animals to men For practical application to human nutrition, confirmation of such observations and conclusions with human subjects would seem to be highly desirable

Chapter II

DIET IN A COLD ENVIRONMENT

THE PHYSIOLOGICAL EFFECTS OF COLD

One might expect that the physiological effects of cold would be directed toward an increase in the metabolic rate through voluntary or involuntary action, and to a decrease in heat loss from the surfaces of the body through postural and vasomotor adjustments

1 BASAL METABOLISM Observations on the metabolism of the laboratory rat after previous exposure to cold have revealed a marked stimulation when the measurements are made under basal conditions (*see, for instance*, Benedict and MacLeod, 1929) However, Treichler and Mitchell (1941) found that this elevation in basal metabolism following cold exposure was exhibited only when the caloric intake of the rat was increased in response to the increase in caloric requirements Hence, the increase in basal metabolism is a direct dietary effect, and only indirectly an effect of a cold environment Similarly, the elevated metabolism of the Eskimo reported by Krogh and Krogh (1914–15) by Heinbecker (1928) and by Crile and Quiring (1939), is probably the direct result of a high protein dietary (Heinbecker, 1931), not of cold *per se*

2 THE COLD STIMULUS TO METABOLISM During exposure to

cold, the metabolism of animals is increased independent of *voluntary muscular activity so that the "resting" metabolism may* amount to four times the basal rate (Giaja, 1925) or as much as five times in man during shivering (Adolph and Molnar, 1946) In a moderately cold environment, the metabolic stimulus is more potent on the sleeping than on the waking subject (Stillman and Lawrence, 1925) According to Burton and Bronk (1937) and Spealman (1945a), shivering occurs when the rectal temperature descends to some critical level, perhaps characteristic of the individual Apparently an increase in metabolism induced by cold, unaccompanied by increase in muscle tonus or by shivering, does not occur to any considerable extent, and is not an important item in the body's protection against cold (Hemingway and Hathaway, 1941) Whether "chemical regulation" of body temperature in the Rubner sense of the term actually exists, cannot be decided from the results of experiments in which variation in muscle tone is not accurately measured Glickman (see Keeton and Mitchell, 1944, p 36 and chart 2) has found a correlation of + 0 930 ± 0 012 between the heat production of human subjects exposed to cold and the action potential of the muscles for a range in heat production from 43 to 108 cals per m^2 per hour The regression of one variable on the other was linear and the fact that the linear relationships extended down to metabolic rates approximately basal *in magnitude would lend support to the belief that the elevation* in heat production brought about by cold is traceable to the contractile function of the muscles

The metabolic mixture from which the energy resulting from cold stimulus is derived even when shivering supervenes, is the same as that prevailing before cold exposure This conclusion of Swift (1932) was based upon careful measurements of the respiratory quotients of human subjects, with due regard for the disturbing effects on this quotient of the change in respiration that may follow exposure to cold The very low R Q's that have been reported for the dog in a condition of extreme hypothermia (Finney, Dworkin and Cassidy, 1927) obviously do not possess a simple metabolic interpretation The changes in blood sugar level on cold exposure do not seem to be consistent in the report of Keeton and Mitchell (1944) no considerable or consistent

effect was observed, although Leonhardt (1941) noted a distinctly increased level on the local application of cold In cats with adrenal glands intact, which have been rendered hypoglycemic to the convulsive level by insulin, exposure to cold induces shivering and a rise in blood sugar to normal or even hyperglycemic levels (Britton, 1928, Onelu, 1941) If the adrenal medulla is inactive, the recovery of blood sugar level does not occur, according to Britton, but does occur, according to Onelu In the chicken, hypothermia may result in a lowering of blood sugar (Rodbard, 1947a) Henriques, Henriques and Selye (1949) have concluded from experiments on rats that cold exerts a specific action in depressing the production of blood fibrinogen

The physiological response to the cold stimulus is evidently mediated through the thyroid glands (Ring, 1942, Starr and Roskelley, 1940 and Leblond *et al* 1944), the adrenals (Britton, 1928) and the pituitary (Tyslowitz and Astwood, 1942) The adrenal cortical hormones in the rat seem to function in protection against cold through a mechanism that is not developed before the 16th day of life (Holtkamp *et al* 1949) Dorfman, Horwitt and Fish (1942) have established the presence in human urine of a cortin like substance capable of prolonging the life of adrenalectomized rats exposed to cold This substance may be a cortical steroid (Dorfman *et al*, 1946) Cold exposure regularly increases the urinary output of 17 ketosteroids in normal men (Freeman, Pincus and Glover, 1944) Exposure to cold induced an increase in the liver fat of fasted mice according to Levin (1948), an effect apparently mediated by the adrenal cortex

The erect posture in man is maintained with greater ease and with reduced cardiovascular demands after a cold bath at 18°C (64°F) (Horvath and Botelho, 1949)

3 Lower limits of tolerable temperature The minimum temperature to which the body of homeotherms may be reduced by severe exposure to cold especially immersion in cold water, and still permit recovery in the large majority of cases on rewarming has been placed at 77°F for the dog by Woodruff (1941) From records of shipwreck survivors in the Bureau of Medicine and Surgery of the U S Navy, Molnar (1946) concluded that probably no man immersed in water can survive a rectal tempera-

ture of 75°F (see, also, Scheinss, 1943, and Spealman, 1946) Obviously, a time factor should be involved in any such estimates The increase in metabolic rate induced by cold may reach a peak of six times the basal, but when the body temperature falls, the heat production also falls until at rectal temperatures of 80° to 85°F, the metabolic rate is about basal in magnitude according to Molnar

Penrod (1949) studied the relation in lightly anesthetized dogs between oxygen consumption and depression in body temperature induced by immersion in cold water Oxygen consumption varied directly with the shivering response until a rectal temperature of 23°C (73°F) was reached Below this temperature shivering is no longer a factor, the oxygen consumption of all dogs fell to approximately one-third that of the pre cooling control level Working with rats, Swinyard and Toman (1948) observed that the minimal electroshock threshold varies directly with body temperature during cold exposure, as well as during experimental hyperthermia

The median lethal temperature of mature rats immersed in cold water for two hours, was found by Adolph (1948) to be about 59°F Resistance to cold was found not to be modifiable by any of a number of factors studied, and apparently depended upon delays in the cooling of essential tissues

4 Sweat secretion Although sweating is not ordinarily associated in one's mind with a cold environment, it becomes a serious problem when men in arctic clothing are required to perform considerable muscular work Siple (1945) has discussed this situation from the standpoint of clothing, and the great importance of "under dressing" during periods of muscular activity in order to avoid accumulation of sweat in the clothing According to Siple, there are two natural boundaries which limit the extreme rate at which the body can be cooled The first is when cooling exceeds 1200 calories [per m²/hr], causing human flesh to freeze upon exposure The second boundary is when the air temperature drops to between −50° and −60°F Then exercise no greater than fast walking, creating deep breathing, may cause hemorrhage in the bronchial tubes

The subject is further considered by Belding, Russell, Darling and Folk (1947a, 1947b) Sweating is shown to be an inefficient way of body cooling when men are heavily dressed in the cold, because much of the sweat evaporated from the skin is condensed in the outer layers of clothing The amount of heat thus recontributed is proportional to the ratio of the amount of insulation lying outside the point of condensation to the total insulation In subsequent periods of inactivity this condensed moisture impairs the insulating capacity of the clothing For men wearing the Arctic uniform and exposed to a temperature of 0°F, the moisture loss from the body is all 'insensible perspiration' until the rate of energy production is equivalent to about 175 cals /m^2/hr (3 7 met) [1] Thermal sweating appears as energy production rises from 3 7 met to 5 0 met, while from the latter point to one of 8 0 met, the relationship is a linear one At 8 0 met, the sweat production may amount to 1000 gms per hour The water-soluble nutrients that are lost in this water output will be considered under Chapter III entitled Diet in a Hot Environment"

5 WATER SHIFTS IN RESPONSE TO COLD Exposure to cold causes certain shifts in the body water that seem important in adjustment to the new environment A moderate loss in blood volume occurs, but according to Frazier (1945), blood water does not migrate to the skin and subcutaneous tissues, since these tissues become dehydrated on exposure to cold He considers this dehydration an important protective measure against freezing of the skin

There is a diuresis in response to cold, similar in character to water diuresis and hence apparently controlled by the pituitary gland (Bader, Eliot and Bass, 1949) There seems to be no relation between changes in urine output and in plasma volume (Eliot, Bader and Bass, 1949) MacKay, Hall and Smith (1934–35) observed a severe renal lesion in rats exposed to cold

6 GASTRIC EVACUATION TIME In dogs a cooling environment decreases the gastric emptying time, according to the observa-

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1 met (Gagge Burton and Bazett 1941) is equivalent to a metabolic rate of 50 cals m^2 hr the metabolism of a resting subject in a sitting position

tions of Sleeth and Van Liere (1937a) and of Olevskiĭ, Zelenko and Kuz'menko (1936) According to the former observers 'this work gives experimental evidence for the basis of the recognized fact that an individual often feels more hungry during cold weather and less hungry in extremely warm weather" But whether these observations apply to man is doubtful in view of the report of Henschel, Taylor and Keys (1944) that an elevated environmental temperature will generally (16 of 17 subjects) decrease the gastric emptying time in man, while in the dog a hot environment will prolong gastric evacuation (Sleeth and Van Liere, 1937a)

7 THE PATHOLOGY OF COLD Gosselin (1949) has described the effects of acute hypothermia in guinea pigs, and has advanced the hypothesis that damage sustained during severe chilling impairs the capacity to repay a thermal debt' Delayed fatalities, 10 to 15 hours after the immersion in cold water probably represent controls different from those operating at the lethal temperature during cooling Kreyberg (1949) has published a very complete review of acute tissue damage due to cold Horvath and Freedman (1947) studied the influence of cold upon the efficiency of men The reaction time to visual stimuli was not altered during continuous exposure to low temperatures for eight to fourteen days, but in a short time the dexterity of the fingers and hand strength were markedly diminished Muscular fatigue (Giaja, 1932) and nutritional anemia (Manville and Chase, 1937) impair resistance to cold Uttley (1948) describes the post-mortem findings in the case of three girls who died of cold exposure in New Zealand The author found that severe cold causes an increased permeability of the minute blood vessels, so that plasma passes through the walls and the red cells are left tightly packed in the vessel, forming a mechanical obstruction to further flow of blood This in turn produces anoxemia and tissue damage

The pathology of cold exposure is discussed by Friedman (1946), Schneider (1946) and Talbott (1944a) Attention may also be called to the book by Luyet and Gehenio (1940) *Life and Death at Low Temperatures*

THE EFFECT OF COLD ON NUTRIENT REQUIREMENTS
ANIMAL EXPERIMENTS

1 ENERGY REQUIREMENTS The energy requirements of animals are increased in response to a cold environment in proportion to the increase in metabolic rate The zone of thermal neutrality, within which temperature exerts no stimulating effect, is shifted downward in the temperature scale as the metabolic rate is increased by muscular activity or the ingestion of food In animal husbandry practice, it has been well established (see citations from Black and Swift, 1943) that fattening steers and well-fed dairy cows produce as economically from the standpoint of feed costs, when housed in an open shed, with protection only from wind and rain, as in a heated barn In a laboratory experiment, Swift (1944) showed that the critical temperature of the fasting mature albino rat is lowered 1°C by the consumption of a high-protein diet in amounts to maintain body weight In animals with a greater specific dynamic action of food, the depression of the critical temperature by feeding would be expected to be greater

The increased metabolism induced by cold is associated in the rat with a marked hyperplasia of the thyroid gland, a hyperplasia that can be prevented by the administration of iodide (Lesser, Winzler and Michaelson, 1949) This observation strengthens the suspicion, originating from the known relationship between the thyroid and the metabolic rate, that exposure to cold may increase the body's requirement for iodine

Herrington (1940) has reported observations on the rate of increase in the metabolism of small laboratory animals at temperatures below the critical, in the fasting condition and with activity restricted only by the small size of the cages Below the critical temperature the relationship between metabolic rate and temperature was linear for mice, rats and guinea pigs, and the increments in metabolism per m^2 per 24 hours per 1°C drop in environmental temperature were 46 3, 43 2 and 26 1 cals for mice, rats, and guinea pigs, respectively It may be computed that the increase in the fasting resting metabolism per m^2 body surface

per day per °C drop in environmental temperature is 51 3 cals for a mature pig (Capstick and Wood, 1922) and 24 6 cals for the mature hen with winter feathering (Mitchell and Haines, 1927), assuming the applicability of Newton's law of cooling bodies to the animal at its critical temperature

2 VITAMINS Some recently reported experiments on rats and guinea pigs indicate that cold exposure of these animals may modify their requirements for ascorbic acid With rats, animals able to synthesize ascorbic acid, Dugal and Thérien (1947) observed a large increase in the ascorbic acid contents of certain tissues (kidneys, liver and testes) on prolonged exposure to temperatures of +4° to −4°C, if the animals adapted themselves well to the changed environment, otherwise, a decrease occurred If the rats adapted to the low temperatures received daily supplements of ascorbic acid, the increase in tissue ascorbic acid were much smaller These results were confirmed with guinea pigs, animals unable to synthesize ascorbic acid, in that resistance and adaptation to a cold environment (+8° to −8°C) depended on the amount of ascorbic acid received daily in the diet, which was varied from 0 5 mg to 75 mg Adaptation to cold was measured by body weight changes and improved even up to the highest vitamin dosage (Thérien and Dugal, 1947) The typical enlargement of the adrenal glands under the influence of stress is completely prevented in rats and guinea pigs exposed to cold if they receive large doses of ascorbic acid The resistance of the animals to cold is inversely related to the size of the adrenals (Dugal and Therien, 1949)

The observations of Grab and Lang (1946) concerning also the problem of the relation of ascorbic acid to cold resistance, bear a different interpretation Working with guinea pigs, their plan involved feeding three groups of animals, on diets differing only in their contents of ascorbic acid, for four weeks *ad libitum* in a room at 20°C, they were then exposed to 0°C until death The levels of ascorbic acid tested were 3 and 30 mg daily The daily loss of weight and the survival time were significantly less for the animals receiving no ascorbic acid than for the other groups, but increasing the daily ascorbic acid supplement from 3 to 30 mg brought about no significant improvement in resist-

ance to cold In these experiments, ascorbic acid was a factor in cold tolerance only to the extent that it was needed to cover the requirement at moderate temperatures, there being no indication that cold exposure increases this requirement In these experiments the loss in body weight during the period of cold exposure was correlated with the survival time In the authors' opinion a low rate of weight loss means a relative inability to draw upon tissue reserves for energy to meet the increased requirements of a cold environment

A similar experiment by the same authors (1944) showed that a dietary deficiency of vitamin A or of vitamin B_1 impaired the resistance of rats to cold The effect again did not seem to depend upon some intrinsic property of the vitamins, but upon the ability to draw upon energy reserves in the tissues

3 PROTEINS An earlier study by Lang and Grab (1944) on growing rats, indicated, though not too surely statistically, that inadequate levels of dietary protein (6 and 9% of the dietary energy) were less favorable to cold resistance than more nearly adequate levels (12 and 15% of the dietary energy) The plan of the experiment was similar to their ascorbic acid work In very well controlled experiments, Lathe and Peters (1949) showed with rats that exposure to a moderate degree of cold will increase the output of urinary nitrogen and presumably the rate of protein catabolism, with simultaneous loss in body weight This may be merely an expression of an increased metabolic rate associated with an inadequate caloric intake

THE EFFECT OF COLD ON NUTRIENT REQUIREMENTS EXPERIMENTS ON HUMAN SUBJECTS

1 ENERGY REQUIREMENTS The basal metabolic rate of the nude human body increases as the environmental temperature drops below the critical (Hardy and Soderstrom, 1938), the increase being linear But this relationship has little significance in practical nutrition, because the human animal protects himself against his environment by wearing clothing, and varying his clothing with changes in his environment The seasonal variation

in basal metabolism of clothed women in a temperate climate is inconsiderable (within a range of 15%), with the lowest average values in the winter rather than in the summer (Gustafson and Benedict, 1928)

The effect of extremes of climate on the total caloric requirements of man has not been studied in a quantitative fashion until the late war In 1946 Dill, Johnson and Kark prepared a critical review of the nutrition of United States and Canadian soldiers stationed in climates ranging from the arctic to the tropics For the purpose of comparing diets in different climates (Johnson and Kark, 1947), data were selected only from groups of men receiving ample rations of wide variety and of such quantity that more could have been eaten if desired In these selected data, a striking correlation is evident between the average voluntary caloric intake and the mean environmental temperature to which the groups of men were exposed The range in caloric intake was from 3100 cals daily in the desert (mean temperature, 92°F) to 4900 cals daily in the Arctic (−30°F) The regression of daily caloric intake on mean environmental temperature was 15 5 cals per °F change in temperature

According to the authors of the report "This very large difference in caloric intake cannot be explained in terms of changing basal metabolic rates (DuBois, 1936), which vary at the most by 20% between arctic (Greenland) and tropical (Java) environments (equivalent to only 400 calories/24 hours), nor can it be explained in terms of difference in body size (Table I) or in terms of different activities since the ground troops carried out much the same tasks in all environments We have no crucial evidence to decide this latter point, but we believe that the caloric expenditure for a given task is greater in cold than in warm climates because of the hobbling effect of arctic clothing and equipment In addition more heat is required in cold than in warm environments to maintain thermal equilibrium "

In a later report, Gray, Consolazio and Kark (1947) present direct experimental evidence of the effect of clothing on caloric requirements In these experiments five young healthy men performed the same amount of muscular work (pedalling a bicycle ergometer and clearing an obstacle) at three different tempera

that the average body weight of the men in the coldest climate is about 8 kgms heavier than that of the men in the hottest climate The general conclusion of these experiments that a cold environment increases caloric requirements is confirmed by the observations of Swain and associates (1949) on the food consumption of soldiers in the sub-arctic climate of Fort Churchill, Manitoba, Canada However, the crude methods that must be used in estimating the caloric intakes of large groups of men have not detected correlation of energy intake with climate when temperature differences are not extreme (Schor and Swain, 1949) Possibly under these conditions appreciable differences in energy requirements do not exist

The great importance of maintaining an adequate caloric intake of men in polar and subpolar regions is emphasized by the field tests on military personnel reported by Kark, McCreary, Johnson, Melson and Richardson (1944) A ration of high acceptability is indicated in such cases It may be interpolated here that the evils of over-weight and over-eating that over-burden the heart and shorten the life in a temperate climate may be mitigated in a cold climate by the extra insulation afforded by a thicker layer of subcutaneous fat

2 WATER AND SALT REQUIREMENTS Besides the effect of cold on the energy requirements of man, there is an effect upon water requirements in so far as the vaporization of water from skin and lungs is diminished and, in both water and salt requirements, in so far as the activity of the sweat glands may be suppressed or stimulated The estimate of Adolph (1933) that in temperate climates the water requirement of man approximates 1 cc per calorie of heat produced, is evidently not applicable to an arctic environment.

THE EFFECT OF DIET ON TOLERANCE TO COLD ANIMAL EXPERIMENTS

1 FATS, CARBOHYDRATES AND PROTEINS Experimental study of a possible relationship between the nature of the food supply, with reference to the three main classes of organic nutrients, and

tolerance to cold seems to have been largely undertaken with laboratory animals, until recently at least Leblond, Dugal and Thérien (1944) noted the free choice selection of proteins, carbohydrates and fats made by nearly mature albino rats when exposed to a temperature of −2°C. It was observed, with only six experimental animals however, that the more fat and the less carbohydrates voluntarily consumed, the higher was the tolerance to cold as measured by body weight changes and survival time. The relative intake of protein seemed immaterial provided a certain minimum proportion was consumed. In experiments on large numbers of rats, Dugal (1944) observed that the consumption of a diet high in fat was associated with distinctly lower mortality rates in the cold (−1°C.) than was that of a diet containing a lower proportion of fat. In control rats maintained at comfortable temperatures, the two diets were equally satisfactory. In a later report to which reference has already been made, Dugal and Thérien (1947) present evidence that seems to confirm the obvious interpretation of the previous experiments, that dietary fat is much more beneficial than carbohydrate in promoting survival in the cold. The observation is reported that in rats the increase in ascorbic acid content of the tissues is smaller with a diet rich in fat than with a diet rich in carbohydrate. The situation may be interpreted to mean that the more difficulty the rat experiences in surviving intense cold or in adapting to it, the greater is the increase of ascorbic acid in its tissues.

The uncertainty that seems to be inherent in the interpretation of the results of feeding experiments on animals in which the experimental diets are allowed *ad libitum*, is illustrated by a comparison of the results secured by Leblond, Dugal and Thérien (1944) with rats and those of Donhoffer and Vonotsky (1947a) with mice. The purposes of the two experiments were the same, namely to study the effect of environmental temperature on food selection. The technics were not the same in that in the Canadian experiments the proteins, carbohydrates and fats were offered separately, while in the Hungarian experiments the mice were allowed their choice of three diets, each containing one third of a standard mixture and two thirds of either starch, casein or lard. In the Canadian experiments the animals preferred fat in securing

extra food energy in the cold, while in the Hungarian experiments they obtained their extra calories exclusively from starch, after a transient initial preference for fat A more intensely cold environment was selected for tests in the Canadian (−2°C) than in the Hungarian (10°−11°C) investigations, and the control temperatures were similarly related, i e, "normal" room temperature and 29°−33°C In both cases the energy requirements and the calorie intake were markedly increased at the lower temperature The interpretation in the one case, supported by independent evidence, is that rats select fatty foods in a cold environment, because thermal equilibrium can be maintained better on fatty than on carbohydrate or protein foods In the other case, the authors are more conservative, merely offering the suggestion that this change in appetite is due to [illegible] in external temperature and [illegible] roid gland (Donhoffer and Vonotsky, 1947b) In unpublished experiments from Keeton's laboratory, no consistent effect of a change in environmental temperature from ordinary room temperature to 2°C on the free selection of protein, carbohydrate and fat was noted with adult albino rats

The investigations of Giaja and Gelineo (1934) were concerned with observations on the survival times of rats in the cold when fasting and when offered individual nutrients Proteins afforded *practically no protection over no food at all* Fat was considerably better in this respect, but carbohydrate gave the best average survival time of all Within the zone of thermal neutrality, these differences did not appear The body weight losses of the different groups of rats were directly correlated with the survival times The ability to survive seems to depend on the ability to metabolize *body tissues for the production of heat* Unfortunately, for the complete interpretation of these experiments, the food intakes of the experimental rats are not reported

Another approach to the same problem has been referred to above, i e, to observe changes in the metabolic mixture undergoing oxidation in the tissues, induced by exposure to cold These *changes are revealed presumably by changes in the* respiratory quotient or by changes in tissue composition However, evidence of this type is confusing Kayser (1937) observed in the guinea

pig a decrease in R.Q. on cold exposure, indicating a preferential combustion of fat; Herrington (1940) observed no effect of environmental temperature on the R.Q. of mice, rats and guinea pigs; working with the rat, Samaras (1939), from observations on changes in tissue composition, emphasized the importance of carbohydrate in combating the stress of immersion in cold water, especially the initial stress; the report of Cohn and Gessler (1925) indicates the non-participation of protein in the enhanced metabolism of dogs induced by cold. The latter conclusion is opposed to the finding of creatinuria by Samaras in his rat experiments, unaccompanied by an increase in urinary creatinine.

The reported effect of dietary fat on the thyroid gland, a gland that seems to be involved in the enhanced metabolism brought about by cold, is pertinent to this discussion. The Mellanbys (1921) working with puppies, McCarrison (1922) and McCarrison and Madhava (1932) experimenting with birds, reported hyperplasia of the gland when the diet contained fat, particularly butterfat or oleic acid. The results were not confirmed by Remington (1938) in experiments on the rat, either on an adequate or on an iodine-deficient diet. The prolonged administration of thyroxine to mice greatly increased food intake (Donhoffer and Vonotsky, 1947b), and free selection provided, mainly, in many cases entirely, by the extra consumption of starchy foods.

Moya and associates (1948), working with adult male albino rats, observed a greater adrenocortical stimulation on exposure to cold when the animals were subsisting on a high-protein diet than when they were consuming a low-protein diet. After the removal of one adrenal gland, followed by cold exposure, the degree of compensatory hypertrophy of the remaining adrenal was higher on the high-protein diet

The importance of fat in the proper nutrition of the skin was revealed by the observation of Williamson (1941) that rats on a fat-free diet developed an abnormal skin, the stratum granulosum becoming especially distinct and the horny layer thick. As the area of contact with the environment, the skin is an important tissue in mitigating the effects of climatic stress. Its response in structure and composition to dietary modifications is worthy of much additional study.

2 VITAMINS Gyorgy (1938) has called attention to the earlier appearance in rats of acrodynia induced by pyridoxine deficiency in a cold room at 40°F than at normal temperatures In particular he points out the striking similarity between this disease in the rat and the syndrome of chilblain in man, suggesting to him that susceptibility to chilblain may be a function of pyridoxine reserves in the body, and that pyridoxine medication may be of value in the prevention of chilblain In much the same vein, Champy and Coujard (1940) associate thiamine and frostbite, in that symptoms resembling frostbite may be produced in thiamine deficient but not in normal, pigeons by immersing the feet in cold water Maycock (1943), however, could not detect in rats any favorable effect of thiamine administration on survival after cold shock, or recovery from this condition

Blaizot and Blaizot (1948) have reported that rats exposed to temperatures of 2° to 12°C develop a marked creatinuria The administration of thiamine prevents this effect The authors conclude that thiamine may either inhibit the secretion of thyroxine, or may spare thyroxine by facilitating the oxidation reactions of thermogenesis

THE EFFECT OF DIET ON TOLERANCE TO COLD EXPERIMENTS AND OBSERVATIONS ON HUMAN SUBJECTS

1 FATS, CARBOHYDRATES AND PROTEINS FREQUENCY OF MEALS The experiments above reviewed suggest strongly that the character of the diet, as well as the amount consumed, may determine to some extent the capacity of the animal organism to resist the damaging effect of cold In particular, the superior effect of fat and of carbohydrate food over protein food is rather clearly indicated Whether the same distinction exists among the main classes of organic nutrients in human nutrition will be considered first on the basis of uncontrolled observations of the food habits of human populations

While scouting the common belief "that people like fat in cold weather and dislike it in hot" in his Arctic Manual (1944a), Stefansson (1944b) summarizes the experience of arctic explorers on

this point as follows: 'We find, on an exclusively carnivorous diet, that if you derive less than 60% of your calories from fat you begin to have a feeling of dissatisfaction, when you derive only 20% or 30% of the calories from fat, you are constantly uncomfortable. There is in the northern woods a term 'rabbit starvation' which refers to a sickness and sometimes death, which results from an attempt to get along on lean without fat.' The advantages and disadvantages in the arctic diet of a high fat food, "pemmican," first prepared by the North American Indian, have been debated by Stefansson (1944c) in the affirmative, and Johnson, Consolazio and Robinson (1944), Kark, Johnson and Lewis (1945) and Lockhart (1945) in the negative, though they are not talking about the same article of diet except in name. Lockhart summarizes concisely the basic requirements for a trail ration in the Antarctic: lightness, high energy value, stability, nutritive value, tastiness and simplicity. Non-fragility and proper packaging are emphasized. An increased proportion of fat calories is recommended, not on nutritional grounds 'but because observations on diets consumed in cold climates indicate that a larger quantity of fat can be consumed with no deleterious effect.'

Frazier (1945) writes as follows from the experience of the United States Antarctic Service Expedition of 1939–41: 'Individuals who had an abhorrence of fats at home would eat butter and fat meats in great quantities.' Skarland (personal communication), Professor of Anthropology at the University of Alaska, from admittedly uncontrolled observations in Alaska, states: "As far as white people and other recent arrivals in the Arctic are concerned, I am convinced that the cold environment modifies the food habits to a great extent. People living out of doors under sub zero temperatures almost invariably develop a strong 'fat hunger,' 'meat hunger' or 'candy hunger.' The only way to satisfy this in the Arctic is to eat more fat food of animal origin, although fats of vegetable origin might serve as well. Vegetarians have difficulties under field conditions although they can do quite well in the towns where imported foods are available." However, 'People who have recently arrived from warmer climates have about the same resistance to cold as those who have lived for years in northern regions.' In a temperate climate, a high fat diet

(71% of calories) is not well tolerated and possesses many disadvantages (Consolazio and Forbes, 1946)

According to Corcoran and Rabinowitch (1937), the Canadian eastern arctic Eskimo, consuming large amounts of meat and fat possesses not only a very active but also an unusual mechanism for utilization of fats, characterized by low levels of total lipids in the blood, a high ratio of phospholipids to total cholesterol and *low cholesterol values, after the ingestion of 200 ml of soybean* oil The absence of ketosis was also noted as unusual

On the other hand, Johnson and Kark (1947), in their survey of the voluntary food consumption of United States and Canadian troops stationed in widely different climatic regions, showed that regardless of environment, the proportions of food calories derived from proteins, fats and carbohydrates were much the same Certainly there was no tendency for these men to consume more food energy as fat in arctic and subarctic regions than in temperate regions These observations were confirmed by later similar surveys reported by Swain *et al* (1949), and by Schor and others (1949)

An experimental approach to the problem of the effect of dietary modifications on man's tolerance to cold was carried out during the war in the Research and Educational Hospital of the University of Illinois in Chicago by a group of investigators headed by Keeton The experiments were based upon the probability revealed by the investigations on laboratory animals above reviewed, that the character of the diet may determine to some extent the capacity of the animal organism to resist the detrimental effects of cold It seemed important to explore this relationship further with human subjects, having in mind particularly the needs of military aviation The effects on cold tolerance as measured by various physiological, psychomotor and intellective performance tests, of modifications in the proportions of protein, fat and carbohydrate *in the diet, were studied on* groups of 10 or 12 young healthy men, they were conscientious objectors to military service who volunteered as subjects The men were clothed in arctic clothing obtained mostly from the Office of the Quartermaster General U S Army, but in most of the experiments the clothing purposely was planned not to protect the men completely

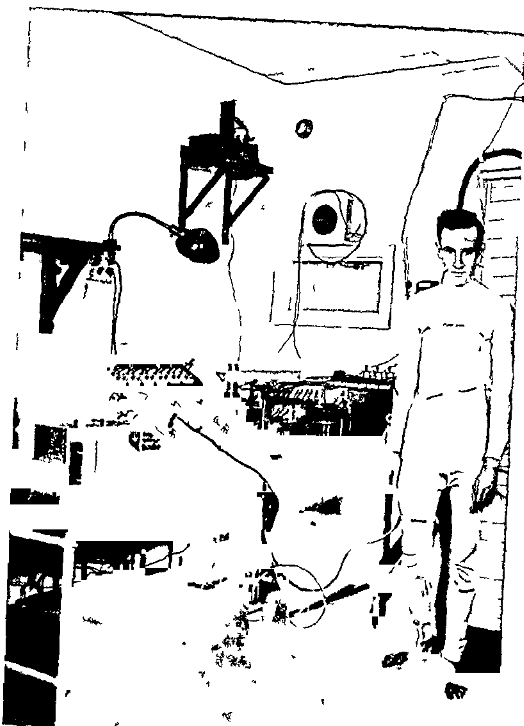


Figure 2 Experiments in a cold environment (−20°F) at the University of Illinois College of Medicine The subject is clothed in a union suit carrying the thermocouples for the determination of temperature at 17 points on the skin (Courtesy of Dr R W Keeton)

diet, but only 15 per cent decrement on the high carbohydrate diet in the full clothing tests

The authors conclude from these experiments "The superiority of a high carbohydrate diet over a high protein diet in increasing the tolerance to cold under conditions in which the caloric requirements are just satisfied is associated with, and probably causally related to an increased requirement of food energy and presumably an increased heat production of the man It is not related to the differential specific dynamic effects of the diets as revealed during a six hour period post prandium"

The latter point will be considered further later In practical nutrition, these advantages of the high carbohydrate over the high protein diet must be evaluated in connection with the large difference in diet composition, amounting to some 220 gms of protein and of carbohydrate per 3000 calories

To the reviewers, it seems probable that the differences in caloric intake between the two diet groups in this experiment can account for only a part and possibly a small part, of the differences observed in tolerance to cold Conceivably, the high-protein diet may have depressed muscular activity, either voluntary or involuntary (increased muscle tension, shivering) or both Possibly the maintenance of the glycogen stores in the liver is an important item in cold resistance (Fuhrman and Crismon, 1947) Burton and Murlin (1935) reported a higher heat storage during the second and third hours after a carbohydrate meal than after a meal of meat Although the authors themselves make no point of this difference, a statistical analysis of the data reveals that the probability that random factors alone were responsible for the observed difference is less than 0 01 and may fairly be neglected

In the second report (Mitchell *et al* 1946) of the Illinois experiments on the tolerance to cold as modified by diet, high-carbohydrate and high fat diets were compared Both experimental diets contained approximately the same amount of protein (77 gms) per 3000 calories, but on the same basis the high carbohydrate diet contained 374 gms more of carbohydrate and the high fat diet 168 gms more of fat The food energy required to maintain body weight in the two diet groups averaged less for the high carbohydrate diet but the difference was not statistically

significant During the eight-hour exposure periods in this diet comparison either one meal containing 40 per cent of the day's calories was served midway in the period or three meals each containing 20% of the day's calories, were served at two hour intervals

The effect of cold exposure on rectal temperature was smaller on the high fat than on the high carbohydrate diet, but only when three meals were served during exposure, the decrements in rectal temperature being, respectively, 0 57°C and 1 25°C during eight hours The experimental results established a high probability that a high fat diet is superior to a high carbohydrate diet in maintaining general psychomotor performance and visual efficiency as measured by critical fusion frequency of flicker (P=0 046) the superiority amounting on the average to about 37% With reference to the speed of tapping, the superiority is clear cut (P=0 022)

Decreasing the interval between meals during cold exposure had no favorable effect on rectal temperature changes if the meals are largely carbohydrate in character, but it has a definitely favorable effect if the meals are largely fat in character (average effect equivalent to a saving of 0 43°C in rectal temperature P=0 00015) The same change in dietary regime progressively and markedly increases the favorable effect of meals on the maintenance of psychomotor functioning, but obliterates entirely the differential effects produced by diets differing widely in their proportions of carbohydrate and of fat The improvement in performance amounts to about 30%, but it cannot be entirely attributed to decreasing the interval between meals, since the caloric intake of the three meals exceeded the caloric intake of the one meal by 50%

In neither this experiment nor the preceding one did the character of the meal consumed just prior to cold exposure exert any appreciable effect on cold tolerance, possibly because the tolerance time for the protective clothing extended over the period in which the diet effect would otherwise have been manifested

The authors of the study just described (Mitchell *et al*, 1946), conclude The superiority of high fat meals over high carbohydrate meals in maintaining tissue temperature in a cold environ

ment seems to be related to heat emission rather than to heat production and may involve a temporary deposition of dietary fat in the subdermal tissues following a high fat meal' This suggestion is based on the work of Schoenheimer and Rittenberg (1935), who traced the distribution in the bodies of mice of dietary fatty acids labeled with deuterium The experiments indicate that most of the dietary fat is deposited in the fat depots before it is utilized The fact that a diet difference in decrement in rectal temperature in the cold was demonstrated only when the meals were spaced at two hour, rather than four- or five hour, intervals, conforms with this suggestion The lower the skin temperature of a man in the colder environment, the lower the melting point of the peripheral fats (Schmidt Nielsen, 1946)

Attention may also be called to the investigations of O Connor (1942) and of O Connor and O Donovan (1942) leading to the suggestion that regulation of body temperature is a consequence of the properties of a monomolecular layer of palmitic and stearic acids on the surface of the oxidation catalyst

The favorable effect of multiplying the number of meals and decreasing the intervals between meals may be an important factor in protecting men against cold Haggard and Greenberg (1935) have clearly shown the advantages in physical efficiency and industrial productivity of increasing the frequency of meals

2 VITAMINS The third report of the Illinois experiments on diet and cold tolerance (Glickman *et al*, 1946) was concerned with the effect of high versus low intakes of thiamine, riboflavin, niacin and ascorbic acid The amounts of these vitamins in the basal diet consumed by all subjects were generally two thirds, or less, of the recommended allowances of the Food and Nutrition Board of the National Research Council (Food and Nutrition Board N R C, 1945) for the last three months of the experiment the quantities per 3000 cals of diet averaged 33 mg of ascorbic acid, 1 22 mg of thiamine 1 77 mg of riboflavin and about 11 mg of niacin Half of the subjects received by capsule massive doses of these vitamins

The subjects on the unsupplemented basal diet at no time exhibited clinical symptoms that could be referred to a vitamin deficiency and no biochemical evidence was obtained that the

vitamin levels of the basal diet were inadequate for normal nutrition for a period of three months However, a single or a multiple vitamin deficiency in the basal diet definitely impaired the muscular endurance of the subjects in performing a simple manual operation The addition of the four vitamins under study to this basal diet, borderline in its content of the vitamins, produced no evident favorable effects on the maintenance of thermal balance, or of psychomotor or intellective performance during eight hour exposures to a cooling environment, i e, −20°F with considerable protective clothing or 60°F with little protective clothing The supplementary vitamin dosages very probably minimized somewhat the fatiguing effects of cold on the retino cortical system as this effect is measured by the critical fusion frequency of flicker

Observations possessing the same significance have been reported by Blair, Urbush and Reed (1947) on military personnel at Fort Churchill, Canada, who were continually exposed to an arctic environment In the authors' words 'Limited observations *under these conditions failed to show any value of vitamin supplements* in the Arctic when the normal diet conforms to the recommended dietary allowances of the National Research Council"

An interesting feature of the experiment of Glickman *et al* (1946), in view of the prevailing uncertainty concerning the existence of a true acclimatization to cold (Horvath, Freedman and Golden, 1947), let alone the mechanism by which it is mediated is the clear demonstration of acclimatization After exposure to −20°F with considerable protective clothing, subsequent exposure to 60°F with very little protective clothing induced a smaller decrement in rectal temperature than occurred without this pre-treatment

Some study was made by Glickman *et al* (1946) of the effect of cold on the excretion of some of the vitamins in the urine The results demonstrate that exposure to cold increases the excretion in the urine of N^1-methylnicotinamide in proportion to the cold stress applied and to the dietary intake of nicotinic acid or amide The results suggest that, when the cold stress is sufficiently severe, the output of total nicotinic acid in the urine is definitely, though only slightly, increased, but that cold may actually depress the

urinary output of ascorbic acid The obvious interpretation of these observations is that cold decreases the requirement for nicotinic acid and increases the requirement for ascorbic acid, but until more information is at hand to support the assumption basic to this interpretation that the urinary output of a vitamin under properly controlled conditions is merely a "spill over' of intake in excess of use, conservatism would be in order

Greene (1941) in discussing frostbite, trench foot, shelter foot and immersion foot, lists as possible causes dietary deficiencies of vitamins A, C and P The statement is made without any evidential support " it is clear that a deficiency of one or other of these vitamins is capable of increasing that exudation from the blood vessels which is the most important damaging factor in frostbite and trench foot" According to Bordet and others (1941) the vascular disturbances observed after freezing of extremities may be caused by a high content in the diet of ergosterol, ergotamine, choline and acetylcholine

THERMAL BALANCE IN THE COLD AS AFFECTED BY THE SPECIFIC DYNAMIC ACTION OF FOOD EXPERIMENTS ON HUMAN SUBJECTS

1 General It might be expected that the heating effect of food, a phenomenon that has been studied in a quantitative fashion for almost 50 years, would be an item of importance in the maintenance of the thermal balance of the body in a cold environment That it is an item cannot be doubted, since as much as 15 to 20% of the energy contained in a mixed meal may be dissipated from the body as extra heat over the fasting level of production This extra heat is commonly referred to as the specific dynamic action (SDA) of food, a term originally proposed by Rubner (1902) The production of extra heat is accompanied by a rise in skin temperature (Booth and Strang 1936) the elevation being smaller and deferred longer for obese than for normal persons

The magnitude of the specific dynamic action depends upon many factors, known and unknown The composition of the diet is an important one Protein alone will raise the heat production of a man over the entire period of its action an amount equivalent

to about 33% of the contained calories (Krauss and Rettig, 1929) For fat alone, the value is about 5% (Murlin, Burton and Barrows, 1936), with carbohydrate occupying an intermediate position

For mixed meals consisting largely of fat, Benedict and Carpenter (1918) obtained an average SDA of 2% of the consumed calories, for a predominantly carbohydrate diet, a value of 6%, and for a high-protein diet, one of 12% Essentially the same average results were reported by Wachholder and Franz (1944) on many more subjects Most of these values are probably minimal because the periods of observation were not sufficiently long to measure the total effect The specific dynamic effects of the high protein and high-carbohydrate diets used by Keeton *et al* (1946) were determined on six subjects each and the total effect estimated by fitting an appropriate equation to the data and extrapolating to the post absorptive period The high protein diet, containing an average of 37% of protein calories, exerted a total SDA of 17% of the consumed calories, and the high carbohydrate diet one of about 10% These values pertain to meals containing approximately 1000 cals each The magnitude of the SDA of food, expressed in this manner, decreases with the size of meal (Wachholder and Franz, 1944), until for breakfasts containing only 222 cals, the SDA is confined to the first hour postprandium and is almost negligible (Soderstrom, Barr and Du Bois, 1918) In its effect on the magnitude of the SDA, the protein content of the diet is of paramount importance in human *nutrition* (Jahn and Strossenreuther, 1928)

There is evidence that the basal metabolism and the SDA of protein are inversely related (Baldwin and Shaw, 1938) and that both decrease in old age (Albergo, 1932) Undernourishment seems to affect the SDA of the different nutrients differently (Tsamboulas, 1939) The SDA of protein is not appreciably affected by moderate muscular work (Bahn, 1927)

2 The Illinois experiments The most important information concerning the SDA of food, with reference to the maintenance of thermal balance, relates to the rate of production of extra heat and the change in rate with time postprandium The peak of heat production occurs in the early hours and may reach a

height of 40% over the basal rate (Kaplan, 1933) The most complete information of this description was obtained by the mathematical analysis of the data on high- and low-protein diets used by Keeton and co workers (1946), the analysis was made in a paper by Glickman, Mitchell, Lambert and Keeton (1948) The rate of accumulation of extra calories with time postprandium was found to follow a sigmoid curve with the point of inflection (the point of greatest rate of accumulation) occurring at about 1 5 hours postprandium for the high carbohydrate diet and between 2 0 and 2 5 hours postprandium for the high protein diet The accumulation of extra calories above basal beyond the point of inflection was very well described by the curve of self-inhibiting growth (the law *of diminishing returns*) *as formulated by Brody* (1927) Having determined the constants in the equation from the two sets of data, differentiation of the equations yielded derived equations from which the rate of extra calorie production can be computed (beyond the point of inflection) for any time postprandium The following values relating to meals containing approximately 1000 cals were obtained by solving for rate of extra calorie production at even hours (or half hours) post-prandium—

Hours post prandium	*Extra calories per hour above basal metabolism*	
	High protein diet	*High carbohydrate diet*
1 5	—	21
2 0	33	18
2 5	29	16
3 0	26	14
4 0	20	11
5 0	16	8
6 0	12	6
7 0	9	5
8 0	7	3 0
9 0	6	2 3
10 0	4 5	1 8
11 0	3 5	1 4
12 0	2 7	1 0

Above environmental temperatures at which heat emission from the body exceeds heat production in the fasting man, the SDA of food may reasonably be regarded as a wastage of food energy and even as a burden upon the temperature regulating mechanism in a warming environment Below such temperatures it may serve a useful physiological purpose by sparing body tissues and increasing the tolerance to cold But in either case it is a small item in the energy economy of man After a high-protein meal containing approximately 1000 cals, the maximum rate of extra calorie production for a man weighing 70 kgms is 33 cals per hour, attained two hours after eating, decreasing in five or six hours, the usual period between day-time meals, to 16 and 12 cals, respectively, and to less than 3 cals per hour in 12 hours postprandium After high carbohydrate meals of the same caloric value, the maximum rate is 21 cals per hour, at 1 5 hours postprandium, and the rates after five, six and 12 hours are, respectively, 8, 6 and 1 0 cals per hour Of the many human activities for which Sherman (1945, Table XXIII) gives the caloric equivalent per hour, there is none, when allowance is made for basal heat expenditure, with as low a caloric equivalent as the SDA, even of a high protein meal Thus, the extra calories over basal for standing relaxed are 40 per hour, for hand sewing, 46 per hour, for dressing and undressing, 53 per hour, and for typewriting rapidly, 75 per hour

The difference in SDA between a high protein and a low protein meal of 1000 cals is even more insignificant, starting at 12 cals per hour at the peak, and diminishing to 8 and 6 cals per hour, respectively, at five and six hours postprandium It is not surprising, therefore, that Pitts, Consolazio and Johnson (1944) were unable to detect any appreciable increase in the thermal load of men working in a hot environment induced by an intake of 150 gms of protein daily, as compared with an intake of 75 gms, the caloric intake remaining the same Also, Keeton and co workers (1946) found that the higher SDA of a high protein diet was not the determining factor in the effect upon tolerance to an intensely cold environment of men allowed some freedom of motion Furthermore, Robinson and Lee (1947), working with domestic animals, did not secure any evidence that a high propor

tion of protein in the ration had any significant effect upon the reactions of the animals to heat

3 THE CORNELL EXPERIMENTS Long (1943) has reported the findings in a rather extensive study on three healthy young men, carried out at Cornell University, ostensibly to determine 'The effect of the protein level in the diet on resistance to cold with special reference to the gaseous exchange and the reaction of the body thermostat at low temperatures' Since most of the data presented relate to comparisons of heat production in the lying and standing positions, in the postabsorptive state and one to 2 5 hours postprandium, at temperatures ranging from 60°F to 0°F, and with diets containing from 12 to 30% of protein calories, it may be considered essentially a study of the effect of the specific dynamic action of diets of varying protein content on the energy metabolism of inactive subjects at different ambient temperatures Furthermore, since the metabolism studies 'with food" were all conducted from 1 to 2 5 hours after the noon meal, the peak effect of the SDA only was obtained The two examples of the noon meal given in the report contained approximately 1097 and 1437 cals

The basal metabolism of the men, measured 16 to 17 hours after food, was not appreciably affected by the protein content of the prevailing diet The metabolism from one to 2 5 hours after food was, of course, markedly higher on the higher protein diets The SDA of 220 to 255 gms of protein daily was estimated, from the change in the nitrogen content of the urine in fasting and "with food" tests,[2] to be 22 cals per hour, that for 96 to 104 gms of protein daily, was estimated at 10 cals per hour, 12 cals per hour lower In the inactive state, 12 cals per hour may be a considerable item in the energy economy, but with any considerable activity, its effect would fade into insignificance Using the direct determinations of the SDA of high protein and low-protein meals secured from the data of Keeton *et al* (1946), the difference is 12

[2]The method here used to measure the heat increment of dietary protein (Table 70 Long 1943) implies that all of the energy produced from the protein catabolized in the body above the fasting protein catabolized, assessed at 26 51 cals per gram of extra N in the urine appears as extra heat and is in fact the heat increment or specific dynamic action, of the protein

calories per hour at the peak of heat production, 2 hours after eating, but steadily diminishes to 6 or 7 cals per hour at the time of the next meal

The author concludes "The totality of data on thermal conductivity of body tissues, body heat storage, and heat production suggests that when extra heat was needed by the body for maintenance of vital functions in cold environments, a greater stimulation of the deeper and superficial tissues of the body was obtained from the oxidation of the high protein meals than was obtained from the oxidation of the low-protein meals If the tissues organs and glands of the body required stimulation at the low temperatures imposed in this research to maintain the temperature of the circulating blood at a normal level, then the extra stimulus obtained from ingesting the larger amount of protein calories in the mixed diet was always available"

This conclusion is well substantiated for inactive men in the fasting state or within 2 5 hours after eating, when the SDA of the food is maximal

The following conclusion, to which considerable prominence is given in the text of Long's report is much less obvious 'The experimental evidence obtained in the lying tests at 40°F indicates that the body protection afforded by the clothing alone may amount to about 35% of the total heat increment, resulting from tests in which maximum insulation was combined with high protein meals The remainder of the total heat increments (65%) may be attributed to the protein stimulus In view of these determinations, it is believed that during exposure to cold protein alone contributes something to the physiological comfort of man that is not furnished by clothing or other body insulation alone"

Changes in rectal and skin temperature during several hours of cold exposure, as important indices of the effect of dietary modifications and variable body insulation on the thermal balance, were not made Such temperature recordings were made during the short metabolism periods (eight to 12 minutes duration), but these were considered merely as 'secondary indices of effects of dietary and clothing modifications" During the fasting and with food' tests these indices favored the high protein meals when the subjects were inactive, but during work on the

treadmill the results of which are only scantily reported and discussed, the temperature differences secured on different dietary regimes are generally insignificant in magnitude and they do not always favor the high protein diet

It is unfortunate that more attention was not given to measurements of body temperature changes and changes in physiological and neuromuscular efficiency over considerable periods of time during cold exposure and subsistence on different diets Such measurements are of primary importance in assessing tolerance to cold, they measure the net response of the body to climatic stress, while changes in metabolic rate measure only the direct effects of diet that appear on only one side of the thermal balance sheet It may be significant in Long's experiment that 'Subjective expressions after ingesting the protein meals were not indicative of the measured metabolism In basal experiments the sensory expressions corresponded more closely with the measured metabolism

It seems fair to conclude that the Cornell experiments afford little information on the effect of different levels of dietary protein on resistance of man to cold They do, however, afford important information of the operation in the cold of the differential specific dynamic actions of diets containing widely different proportions of protein To demonstrate these comparatively small thermal effects it was necessary to maintain the subjects in a condition of inactivity

CONCLUSIONS

From the observational and experimental information above discussed, certain definite conclusions seem warranted Certainly a cold environment, in proportion to its severity, definitely increases the caloric requirements of man Its effect upon water requirements is one of depression except in so far as sweating may occur during periods of work of a severity of four met or more when heavy arctic clothing is worn The loss of salt, vitamins and minerals in thermal sweat will be considered later

Diet modifications may definitely affect the tolerance to cold

The Illinois experiments prove definitely that a high carbohydrate diet, which, as a matter of fact, approximates closely what would be considered a typical American diet, is superior in this respect to one that is top heavy in its proportion of protein Whether the observed difference in tolerance promoting potency between these two diets is due to the difference in protein content or to the difference in carbohydrate content has not been determined However, the fact that varying reciprocally the proportions of carbohydrate and fat in diets containing adequate but not excessive proportions of protein does not depress the tolerance promoting effect of the so called high carbohydrate diet, is explained on the premise that only protein among the three main classes of organic nutrients exerts such a depressing effect Dietary fat under some conditions improves still further the relatively beneficial effects of carbohydrate foods The levels in the diet of thiamine, ascorbic acid, riboflavin and niacin, provided they are present in proportions adequate in a comfortable environment seem to exert no appreciable effect upon tolerance to cold

In practical dietetics, it would seem that diets in a severely cold environment are not benefited with reference to effects upon cold tolerance by high intakes of protein The extra calories required in the cold, as compared with the warm, environment might better be covered by an increased intake of carbohydrate and particularly fat, foods The extent to which this recommendation can be put into effect in feeding communities of men will depend upon other than nutritional factors, such as acquired food habits, the expected duration of residence in an arctic climate, the motivation for such residence, and the extent to which the indicated diet can be made acceptable to the palate and maintained acceptable under arctic conditions To the extent that 'fat hunger' develops in men residing in polar and sub polar regions, the indicated changes from accustomed *diets may* the more readily be made

In conditions of inactivity high protein foods may exert a temporary favorable effect on cold tolerance for a short period after consumption, due to their high specific dynamic action, but under conditions of normal activity they might better be eschewed

There is some evidence and considerable rational support for the belief that decreasing the intervals between meals, especially if the foods are rich in fat, may increase their favorable effect on the thermal balance in a cold environment If snacks between regular meals induce a greater caloric consumption, this in itself may be beneficial, but the problem needs further study

Animal experiments support some of the above conclusions, in particular the neutral or unfavorable effect on cold tolerance of dietary protein, but some of the interpretations of these experiments have not been shown to apply to man, in particular the favorable effect of ascorbic acid The apparently contradictory results of many of these experiments, indicate either a defective experimental technic that does not control factors that may dominate the outcome, or the existence of differences among animal species in respect to the relationship of nutrition to climatic stress It seems certain that in this field of research, the information secured from the best controlled animal experiments should not be applied to human dietetics prior to actual field tests It may even be doubted that animal experimentation in this field of research in human nutrition, is a profitable undertaking

Chapter III

DIET IN A HOT ENVIRONMENT

THE PHYSIOLOGICAL EFFECTS OF HEAT

The physiological effects of tropical climate conditions upon man have been reported extensively by Sundstroem (1926) with special reference to adaptation The reviews of Machle (1944), of MacPherson and Lee (1945), of Robinson and Gerking (1947), of Machle and Hatch (1947), of Wakim (1948) and of Winslow and Herrington (1949) may be consulted with profit We would like to call particular attention to the review of Lee (1940) entitled "A basis for the study of man's reaction to tropical climates" This review is a remarkably complete discussion of the subject, replete with critical evaluations of laboratory evidence The logical development of his subject has not led Lee into the exposition of those mathematical relationships between the body and its thermal environment that, however complex, seem still to be undue simplifications of the practical situations that develop in the field As Machle and Hatch state "Man as a functioning organism is quite different in character than any of the systems into which, in an analytic approach, he may be resolved" In a later publication, Lee (1949) depicts by a series of diagrams the interactions of tropical environment and human performance, with both environment and performance broken down into their ultimate factors

1 EFFECTIVE TEMPERATURE There is one relationship, with an empirical rather than a rational basis, that has proved most useful especially in evaluating tropical climates The "effective temperature" scheme was elaborated by Houghton and his co-workers in the Research Laboratories of the American Society of Heating and Ventilating Engineers in Pittsburgh, Pa (see Houghton and Yaglou, 1923) By exposing human subjects, comfortably clothed, to various conditions of temperature, humidity and air motion, when at rest, those zones within which sensations of comfort, or of equal degrees of warmth and of cold, were delineated From the results of a very large series of experiments, an empirical nomogram was constructed (Yaglou, 1926, A S H V E Guide, 1947), permitting the integration of dry bulb temperature, wet bulb temperature and air motion into a single term, the "effective temperature" The effective temperature (E T) may be defined as that temperature of a still, saturated atmosphere that would produce the same sensations of warmth or cold as the given combination of dry and wet bulb temperatures and air motion, for men at rest and comfortably clothed Yaglou (1926) has developed an effective temperature nomogram for men at hard work, stripped to the waist

2 SWEAT SECRETION The exposure of man to a hot environment induces a series of adaptive responses, including, first, those responses aimed at increasing heat loss from the body These responses include elevation of body and skin temperature, vasodilatation, increased heart rate, water shifts and sweating Man shares with the Equidae the ability to increase enormously the loss of body heat as the heat of vaporization of water by the action of sweat glands distributed over large areas of the body surface This is an emergency mechanism thrown into operation when the heat emission from the body fails to keep pace with its heat production as in a tropical environment, or when heat production is elevated by muscular activity to the point where heat loss by radiation, conduction and convection cannot maintain thermal equilibrium

The precise relationships between the initiation of sweating and body and environmental conditions and between the rate of sweating and environmental conditions is obscure It may involve

genetic and constitutional characteristics, since all observers have noted wide variations in sweating among different (and normal) individuals in the same environment. The physiology of human perspiration is dealt with in a scholarly manner by Kuno (1934), who distinguishes two types of sweat glands, the apocrine glands in the axillae, the palms of the hand and the soles of the feet responding to an emotional stimulus only, and the eccrine glands, located in the other areas of the body (and the axillae) and responding to a thermal stimulus.

The histophysiology of sweating in the lower animals has been recently discussed by Sperling and Koppanyi (1949). Attention may be particularly called to the article of Bunting, Wislocki and Dempsey (1948) on the chemical histology of human eccrine and apocrine sweat glands, as well as reports by Bunting (1948), and Rawlinson and Hankinson (1948) on the association of apocrine sweat glands with the mammary glands of women. A fact of great significance to the question of the function of sweat glands in the excretion of iron is the occurrence of stainable iron deposits in the apocrine, but not the eccrine, sweat glands.

Unclothed men, on the average, will begin to experience a degree of sweat secretion associated with sensations of distinct unpleasantness at the following limits of air temperature and relative humidity (Winslow, Herrington and Gagge, 1937).

Temperature °F	Relative humidity, % saturation	Effective temperature °F
89	96	88
92	70	86.2
95	48	84.7
98	30	83.2
101	19	82.5
104	0	62.5

The average output of the individual sweat glands of the arms and legs of a man at rest in a warm environment is from 0.0037 to 0.0043 mg per minute, according to Randall and McClure (1948). The response of the sweating mechanism to the stimulation induced by mild exercise and by heat is to increase the number of

functioning glands Further evaporative heat loss may be brought about, if the demands of the situation so require, by an increased output of the individual glands

The rates of sweating under maximal conditions of thermal imbalance approximate 4 liters per hour, though a production of 1 liter per hour represents many kinds of work carried out under extreme but tolerable conditions At the same effective temperatures, a hot dry climate, according to Lee (1940, Lee *et al*, 1941), is much more of a thermal load than a hot humid climate and induces a greater flow of sweat, at least in acclimatized men (see also Gerking and Robinson, 1946) Molnar *et al* (1946), from studies in the California desert and tropical Florida, assess the thermal stress of the desert as being three to four times greater than in the tropics, due in part to the solar energy impinging on the human body in the desert Adolph (1938) estimates the maximum radiation impinging upon seated subjects to be 250 kg cals per hour, of which about half is reflected and about half absorbed

In unpublished experiments carried out in the Division of Animal Nutrition at the University of Illinois during the war period, the average hourly secretion of sweat for human subjects, nude or very scantily clothed and at rest in an air conditioned chamber, was 720 gms under hot humid conditions (dry bulb 101°F, wet bulb 91°F, effective temperature 93°F), 414 gms under hot dry conditions (dry bulb 111°F, wet bulb 76°F, effective temperature 87 3°F) and only 117 gms under comfortable conditions (dry bulb 85°F, wet bulb 71°F, effective temperature 77 5°F) A good share of the latter weight loss is insensible perspiration The subjects (six in number) of these experiments, though subjected to heat exposure for eight hours daily five days a week for many consecutive weeks, and four hours on Saturdays, could not be said to be as highly acclimatized as residents of Australia, with whom Lee worked Vernon's observations (1923) also do not agree completely with those of Lee in respect to relative rates of sweating in hot dry and hot humid environments

There are sex and race differences in the response of the sweat glands to sudorific substances, such as acetylcholine introduced by iontophoresis or by injection Females are less responsive than

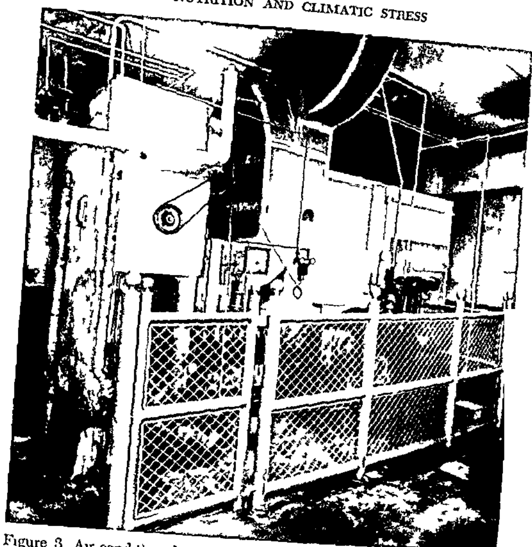


Figure 3 Air conditioned chamber in the Animal Nutrition Laboratory of the University of Illinois showing air conditioning tower air ducts and refrigerator machine This chamber was used in the study of the mineral and vitamin content of sweat secured under simulated tropical and jungle conditions It is also being used to measure the effect of environmental temperature on the vitamin requirements of pigs

males, and the colored race more responsive than the white race (Gibson and Shelley, 1948)

When men work in a comfortable to warm environment, most of the extra heat produced is dissipated from the body as latent heat of water vapor, the emission of sensible heat being but little elevated (Houghton *et al*, 1931) The same investigators have shown that muscular work in a hot environment is associated with a rate of sweat loss greater than the sum of the rates of sweating

produced in that environment at rest and that produced by the same work in an environment which just does not cause sweating at rest This degree of excess sweating varies with conditions and reaches a maximum at moderately high effective temperatures Lee (1940) also gives an illustration of this interesting phenomenon According to Lehmann and Sjakåll (1937a), the quantity of sweat lost per minute per kgm m of work accomplished rises with rising temperature but is independent of the fluid intake

The sweat glands fatigue readily at high rates of sweating (Ladell, 1947) A newly recognized syndrome termed "tropical anhidrotic asthenia," or "thermogenic anhidrosis" has been described by O Brien (1948) This form of heat exhaustion is characterized by a complete failure of sweat secretion apart from some sweating of the forehead and face

3 MUSCULAR ACTIVITY The adaptive responses to heat stress thus far considered relate to mechanisms for increasing heat dissipation from the body, pre eminently the sweating mechanism A second type of response relates to heat production within the body Sojourn in a tropical climate depresses the will to do work both mental and physical Lee (1940) considers this question at some length, with reference to experimental findings and field experiences In himself he notes a definite reduction in mental power and speed in the two climates with an average effective temperature of 77°F " [Singapore and Brisbane in summer]

Concerning the effect of the tropics on muscular activity, Lee concludes 'A review of the evidence, however, suggests that we have three grades of effect—(1) with very light exercise undertaken spontaneously there is a reduced will to work and reduced activity, a truly adaptative phenomenon, (2) with the most severe forms of exercise critical phenomena intervene more rapidly, resulting in fatigue and reduced total energy expenditure, an occurrence adaptative in result though critical in production, (3) with intermediate grades of work, especially those undertaken in response to a demand, there is but little reduction of work capacity and total energy production is not reduced The latter may even be raised owing to a lowered mechanical efficiency In this last field there is no adaptative change The higher the effective temperature, of course, the smaller will become the third category

of work-task, and the earlier will critical phenomena make their appearance."

In a discussion of tropical fatigue and warfare, Lee and Macpherson (1948) report statistical, physiological and psychological observations on 1507 ground crew stationed in southern Queensland. There was no doubt that reduced efficiency was widespread in RAAF ground crew and there was a high incidence of skin disease. 'While climatic effects *per se* can be cited as the major cause of skin affections and a contributory cause of general inefficiency, the observers were led to the conclusion that personal and psychological factors were of paramount importance, and that much of the inefficiency is preventable by realistic handling of these factors."

At the National Hospital of the Medical Research Council of Great Britain, the limits used for assessing the efficiency for work in the heat are given by Ladell (1947) as follows: rectal temperature 38.3°C., sweat rate 1250 ml. per hour, pulse rate 140 per minute, and whether one or more of the subjects in the Heat Physiology Team failed to stay the course for four hours.

4. BASAL METABOLISM. There is a tremendous literature on the effect of a tropical climate on the basal metabolism but the conclusions drawn by different investigators as to the relationship between climate and basal metabolic rate are divergent. To mention only a few of the more recent reports on this subject: Hafkesbring and Borgstrom (1926–27), Drinker (1936) and Mason (1934) observed definite decreases in the basal metabolic rate in tropical environments, of the order of magnitude of 10%. Camis (1936), on the other hand, observed low metabolic rates generally among individuals who had been under tropical conditions for only a short period of time. With longer residence in the tropics, the basal rate was generally higher than those reported in temperate climates. The observations of Camis are directly contrary to the earlier ones of Knipping (1923), who states from observations on 30 subjects [translation]: "In the majority of cases, the basal metabolism is increased during the first weeks of residence in the tropics. On longer residence in the tropics the basal metabolism apparently decreases to the predicted level, and on months or years of residence to significantly lower levels. With European

residents of the tropics, Malays and Southern Chinese, the basal metabolism remains at these low levels (−2 to −16%)" Knipping also reports percentage values for the specific dynamic effect of food in the tropics and concludes that the effect tends to decrease on long residence in a hot climate The reported values lend little support to this conclusion, while their significance as measures of the SDA cannot be assessed in the absence of an adequate description of the method by which they were obtained

With such apparently conflicting evidence before them, reviewers of the literature on basal metabolic rate in the tropics have balanced the evidence as best they could DeMoura Campos (1937) concludes that the preponderance of evidence favors the conclusion that residence in the tropics, particularly in a hot moist environment, lowers the basal metabolic rate and that this is a measure of adaptation to conditions impeding the dissipation of heat from the body Albagli (1949), on the basis of the largest series of basal metabolism measurements ever made in South America, concludes that the basal metabolism of normal, well-nourished individuals is independent of climate, being comparable to the standards in vogue in the United States and Europe

It is interesting to note that Galvão (1947), from very careful measurements on 65 adult male dogs in Brazil, weighing from 3 4 to 31 3 kgms, reports that in this tropical climate, the basal metabolism per unit of body weight is more constant than the basal metabolism per unit of body surface He concludes "If the Rubner Richet law is true only in cold climates, it has a true thermic significance and expresses a causal relationship between heat loss through the surface and heat production" There may be some question whether the relative inconstancy of the basal metabolic rates referred to body surface may not have been caused in part by the inaccuracy of estimates of surface area by the Rubner formula (see Cowgill and Drabkin, 1927)

Galvão (1948 a and b) has extended his observations on basal metabolism in the tropics to lean men and to well-proportioned men The results are in harmony with the conception that the Rubner-Richet surface area does not apply in the tropics With lean men, the basal metabolism in the tropics was found to vary

men with body weight to the 0 78 power Following the ideas of Benedict, Galvão interprets these body size functions as representing the metabolically active weight of lean and well proportioned men, respectively The experiments were carried out on men ranging in age from 20 to 47 years

Lee (1940, p 27) discounts the significance of differences in basal metabolism of men observed in different climates on the ground that they are probably traceable to variations in adventitious activities,' particularly muscle tone The existence or nonexistence of differences in basal metabolic rates in different climates may also depend upon the environmental temperature at the time the measurement is made The true 'basal condition in human physiology at least, is thought of as involving a comfortable environment within the zone of thermic neutrality For nude subjects, DuBois (1936, p 191) defines this zone as between 27° and 34 7°C (80 6° and 94 5°F) For men fully dressed, McConnell, Yagloglou and Fulton (1924) obtained minimal metabolic rates between 75° and 83°F effective temperature On the other hand, many of the published determinations perhaps most were determined at "habitat temperature," to use Benedict's (1938) phrase Thus changes that Mason (1944) observed in her basal metabolism as she travelled by ship from San Francisco to India were associated with increasing ambient temperature and humidity Whether they would have manifested themselves if the measurements had been made within the comfort zone in a metabolism ward is problematical

If the body temperature is modified by climate, the basal metabolism would be expected to change also Using diathermy to induce hyperpyrexia, Christensen (1933) observed an average rise in the metabolism of four men of 10 8% per °C rise in rectal temperature A small part of the elevation in metabolism was due to the increased activity of heart, lungs and glands, according to the author, but the major part was an expression of a heightened cellular metabolism

5 APPETITE AND DIGESTION In Lee's experience (1940), a marked decrease in appetite, ofttimes amounting to revulsion from food, occurred The revulsion passed away with acclimatization, but at no time could the appetite be said to be at temperate

levels" He believes a certain reduction of appetite can justly be regarded as an adaptive phenomenon there will be some slight decrease in heat production The explanation of the impairment in appetite in tropical heat is not clear Among other authors, Borchardt (1930) noted that gastric secretion and motility of both human subjects and experimental animals are decreased in an artificial tropical climate The longer retention of food in the stomach would be expected to induce a less intense appetite for a subsequent meal if not too long delayed, but Henschel, Taylor and Keys (1944) report that, in all but one of 17 young men under observation, the gastric emptying time was faster at the higher temperatures Twelve of the subjects exhibited an average decrease of 30% in the gastric emptying time at 120°F, as compared with that at 77°F However, the ingestion of meals ranging in temperature from −8° to 65°C was found to have no appreciable effect on gastric motility (Henschel, Taylor and Keys, 1949)

6 HYPERTHERMIA Hyperthermia, experimentally produced, has been reported to induce certain changes in blood composition that might bear upon nutritive requirements In guinea pigs, Dobblestein (1940) observed always a lowering of the ascorbic acid content of the blood in artificial fever an increase of 2° to 3 5°C in body temperature was associated with a reduction of ascorbic acid in the blood to a level one-half (or less) of normal Parvis (1941) has reported a decrease in the ascorbic acid content of the organs of guinea pigs maintained at 43° to 45°C The observation of Dobblestein was not confirmed for human subjects by Osborne and Farmer (1942) Using 17 arthritic patients as subjects, no significant changes in the ascorbic acid level of the blood resulted on elevation of the temperature of the body to 104°F and maintaining it there for four hours, using a combination of air conditioned cabinet and inductotherm Aron and others (1946) reported in a study of 92 patients that elevation of the rectal temperature to 106°F by physically induced fever was followed by a depression of the vitamin A and carotene levels in the blood plasma, irrespective of the chemotherapeutic agents given before or during the period of observation The authors state "This behavior of the plasma vitamin A is, to the best of our knowledge, the first biochemical indicator shown to serve as

measurement of the intensity of the action of physically induced fever on the human organism"

If hyperventilation occurs during extreme hyperthermia, the pH of the blood will shift to the alkaline side, due to loss of CO (Bischoff, Long and Hill, 1931, Danielson *et al*, 1938)

7 WORK CAPACITY The total metabolic exchange of men at work in a tropical environment is not increased over that in a temperate environment (Herxheimer, 1933, Ehrismann, 1938), but the capacity for work is less The physical fitness of RAAF ground crew serving in the tropics deteriorates slowly according to MacPherson and Lee (1945) as time in the tropics increases, although in their opinion " over-all deterioration, about which many complain, is highly psychological" Psychomotor efficiency, as measured by time for accurate gunlaying, is depressed under hot conditions (Lee, Klemm and White, 1945) "Reaction times at effective temperatures of 83 5° and 94°F are significantly longer than those at 65°–70°F The increment is 5–12% Within the range of effective temperature, 88°–96°F, when the subject is seated at rest the reaction time does not undergo any further increase with rise of temperature, even when physical failure is imminent" Reed (1942) discusses "tropical neurasthenia," a rather indefinite functional nervous syndrome, which is a recognized disabling disorder of great importance in the tropics It is associated ' with defective psychologic adaptations to environment and stresses of life and characterized by increased fatigability"

Robinson (1942) has presented an interesting illustration of the greater endurance for muscular work, other things being equal, of a small as compared to a large man, under environmental conditions that place a severe strain on the heat dissipating mechanisms of the body There is no difference in muscular efficiency, the determining factor is the greater ratio of body surface to body weight in the smaller man since heat dissipation depends largely upon skin surface while the extra heat induced by muscular work depends largely on body weight

A positive correlation between experimentally induced changes in blood volume (venesection and infusion of serum albumin) and performance in the heat of certain simple physical tasks

ticularly the cardiovascular and vasomotor adjustments, are completed in a few days to a week and are expedited by work However, Mills (1944a) claims that metabolic acclimatization, associated with changes in nutrient requirements in a tropical environment, proceeds at a much slower rate, beginning late in the second week of continuous exposure and being largely accomplished by the end of the third week Heat acclimatization persists for at least three weeks of cold weather, but the benefits decrease from week to week (Henschel, Taylor and Keys, 1943) In the experience of Eliot, Stein and Bader (1948), in men acclimatized to heat, loss of acclimatization was not accelerated by repeated cold exposures, as judged by cardiovascular and metabolic indices and subjective reactions Acclimatization to heat may be maintained for periods of several months by occasional re exposure to the original environmental stress (Stein, Eliot and Bader, 1949)

9 UPPER LIMITS OF TOLERABLE TEMPERATURE The upper limits of temperature and humidity tolerated by men at rest and at work have been estimated, among others, by Yaglou (1945), Bean, Eichna and Ashe (1945) and Eichna, Ashe, Bean and Shelley (1945) The estimates vary as human subjects vary, but there is general agreement that the wet bulb temperature is the limiting factor which determines the ability of men to work in a hot environment (90°F and above) At a dry bulb temperature of 120°F, men can perform moderate work easily at a wet bulb temperature of 90°F, they would work with difficulty at a wet bulb temperature of 92°F, and would find it impossible to continue work at a wet bulb temperature of 94°F (Eichna, Ashe, Bean and Shelley, 1945) Acclimatized men working above the upper tolerable environmental limits develop, according to Eichna *et al*, "marked physiological changes, and undesirable, frequently disabling symptoms similar to those sustained by unacclimatized men when first working in the heat"

The upper temperature tolerance limit for men can be considerably raised by partial immersion of the body, or periodic immersion, in relatively cool water Spealman (1945b) observed that nude men with their lower extremities immersed in water at 86°F can tolerate an effective air temperature of 107°F (127°F

dry bulb, 105°F. wet bulb) as well as men without such expedients tolerate an effective temperature of 92°F. The alleviating action of water at 86°F. sprayed on the body at high air temperatures is also demonstrated.

The increasing difficulties of men working under intolerable conditions of impaired heat dissipation are described by Gerking

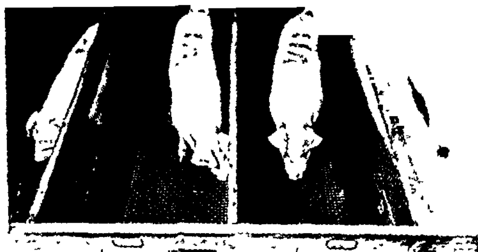


Figure 4 Experimental pigs in the air-conditioned chamber shown in Figure 3 The riboflavin requirement is being studied at 85° F and again at 42° F in this chamber

and Robinson (1946), Ladell, Waterlow and Hudson (1944), and Talbott (1944b), while Heilbrunn and associates (1946) discuss the more general topics of heat death, heat injury and toxic factor Readers interested in this phase of the subject should consult the publications cited The tolerance limits of men to radiant heat as administered in therapeutics has been studied and discussed by Lloyd-Smith and Mendelssohn (1949)

10 Heat injury Lee (1940) classifies the main syndromes of heat injury as follows (1) hyperpyrexia, or true heat stroke, (2) circulatory insufficiency, or heat exhaustion, characterized by lowered blood pressure, (3) hypochloremia, or heat cramps, char-

acterized by a serum chloride concentration of 365 mg per 100 ml or less, and, (4) super dehydration, characterized by reduced salivation, oliguria, uremia and pyrexia

The debilitating effects of dehydration are well assessed by Adolph and Brown (1943) as follows 'The survival of men in the desert without water depends upon (1) endurance (the maximum water deficit tolerable), and, (2) the rate of water loss Most men in the desert for a week can tolerate a water deficit of 5% of body weight without losing their capacities to participate in organized physical activity, but are less efficient than when fully hydrated Between 5% and 10% dehydration, the average man is quite fatigued and spiritless If much physical exertion is attempted, dehydration exhaustion occurs After 10% loss of body weight as water, most men can do little more than a slow walk without a pack For an inactive person, a tolerable water deficit of 20% can be predicted"

One interested in an extensive study of man's response to desert conditions can turn to Adolph's (1947) recently published book with profit

Brown and Towbin (1944) discuss the circulatory stress of heat, work and dehydration in desert troops Daily and Harrison (1948) studied the mechanism of experimental heat pyrexia in laboratory animals and the treatment of human heat stroke suggested by these findings Schmidt-Nielsen and co workers (1948) have described the peculiar and effective protective mechanisms of desert mammals against the stress of heat and dehydration

McCance (1935–36, 1937, 1938) and McCance and Widdowson (1937) have reported extensively on the metabolic and physiological effects of salt deficiency in man (see also Lévy Solal and Laudat, 1935) An interesting relationship between chloride and nitrogen economy has been reported by Conn and Johnston (1945) From long-term experiments on human subjects in a tropical environment they observed that 'a period of negative nitrogen balance is a characteristic phenomenon associated with the process of acclimatization to humid heat This occurs invariably and is independent of the level of dietary protein and salt It is observed at the time that the concentration of salt in urine and sweat are falling It disappears when the adjustment called

acclimatization has been completed It is our belief that an acute physiological load imposed upon the adrenal cortices (by the stress of the new adjustments in electrolyte metabolism made necessary by life in humid heat) is responsible for both findings (decrease in urine and sweat salt concentrations and negative nitrogen balances) *After full acclimatization has been established,* and salt and nitrogen equilibrium are being maintained, a sharp drop in salt intake leads to negative nitrogen balance Under these circumstances, the addition of salt to the diet results in a rapid return to nitrogen equilibrium From a practical point of view, such negative nitrogen balance is quickly abolished in fully acclimatized man when the daily total NaCl intake is raised to 7 grams or above'

Conn and Conn (1941) had previously shown that adrenal cortical extract increases sodium retention and increases the excretion of nitrogen in the urine According to Ladell (1945), desoxycorticosterone diminishes the output of sodium and chlorine in the sweat as well as in the urine In fact, the concentration of sodium in sweat varies with adrenal cortical activity, being low as cortical functioning rises and high as it falls (Conn, 1949) It may be used as Conn proposes, in the diagnosis of diseases of the adrenal cortex such as Addison's disease, and in the control of its treatment According to Nichols and Miller (1948), relatively large amounts of adrenal corticoids occur in sweat induced by exercise or thermal stimulation

An informative table of the physiological responses of acclimatized men to increasing effective temperatures, when at rest and at work may be found in the *1947 Guide of the American Society of Heating and Ventilating Engineers*, page 208 The table gives the responses of pulse rate and rectal temperature, the perspiration per hour, and total work accomplished

THE COMPOSITION OF HUMAN SWEAT AND THE RATE OF DERMAL LOSS OF NUTRIENTS

The composition of human sweat is subject to so much variation that average values for its constituents may be as meaningless as

average values for the composition of human urine It varies with the region of the body wherein the sweat is secreted, with the rate and duration of sweating and the stage of acclimatization It has not been shown to be affected by atmospheric conditions, and its relationship to the food supply is so variable as to defy generalization As Adolph (1923) says 'While the composition of the sweat is correlated slightly with that of the blood, the product elaborated by the sweat glands seems to be primarily independent of chemical conditions in the body This secretion is more dilute than the blood in respect to most dissolved substances The compensating activities of the kidneys which correlates their work with that of the sweat glands, is a correlation only on the part of the kidneys, since the kidneys are accustomed to correct the variations in the blood's composition"

The dissolved substances of sweat possess no known relationship to the function of this secretion in maintaining the heat balance of the body They seem to include all of the constituents that are found in the blood, including all the water soluble minerals and vitamins, and organic metabolites, such as urea, ammonia, uric acid, creatinine, creatine (sporadically), lactic acid and citric acid The occurrence of lactic acid in sweat is particularly interesting, since its concentration in sweat far exceeds that in urine, blood, saliva and cerebrospinal fluid (Horstmann, 1941), suggesting that it bears some intimate relationship to sweat gland activity (Fishberg and Bierman, 1932a, b) Muscular activity will increase the concentration of lactic acid in sweat, especially if the activity is so severe that a "steady state" is not attained (Snapper and Grunbaum, 1929) The fungicidal properties of sweat seem to be traceable to its content of lactic and caprylic acids (Peck *et al*, 1939) Ingested alcohol readily passes over into the sweat in which its concentration may exceed that in blood (Nyman and Palmlov, 1936) For general information on sweat composition, the following references may be consulted Hancock, Whitehouse and Haldane (1929), Chatron (1933), Mosher (1933), Whitehouse (1931, 1935), Hopf (1935) and List (1948)

The excretion of organic metabolites in sweat is merely an accident in the general function of ridding the body of substances of no further use to it Presumably the greater the excretion of urea,



Figure 5 Balance suitable for determining the insensible loss in body weight at comfortable temperatures and sweat loss in a hot environment The balance will weight a man to 0 01 gm For sweat loss measurement the subject would be weighed in the nude or with a minimum of clothing

for example in the sweat the smaller its excretion in the urine If the protein metabolism of the body on a constant intake of protein is increased by the conditions environmental or intrinsic that have induced sweating then the output of total nitrogen in both urine and sweat will increase In particular one would expect an increase in the total output of creatinine by both path

ways Information in the latter category is not available, so that in themselves variations in the output of nitrogenous constituents in the sweat affords no basis for concluding the existence of corresponding variations in protein requirements

For the purposes of this report, the content in sweat of mineral and organic *nutrients* only will be considered It is true that information of this type is not easily interpreted in terms of increased requirements until it has been shown that compensatory changes in urinary output do not occur, or do not completely compensate The hourly output in the sweat of a given nutrient is far more significant in this connection than the concentration in some particular sample of sweat, because (1) the composition of sweat varies in different regions of the body, (2) the method of collection may not avoid the possibility of evaporation and (3) the frequent use of rubber devices for collecting sweat from a limited area of the body, a hand or an arm, may release from the rubber substances simulating in some of their reactions, the nutrient that is desired to be determined, i e , ascorbic acid The best method of collection (Lee, 1940) is to remove the sweat solutes during a definite period of time by thorough washing of the entire body The total weight of sweat can be estimated with small error from the net loss in body weight during the collection period This method was followed in all of the work carried out in the Division of Animal Nutrition of the University of Illinois, the results of which will be summarized below (Mitchell, Hamilton, Shields and Haines, 1943, Mitchell, Hamilton and Haines, 1949)

1 NITROGEN AND AMINO ACIDS As indicated above, the output of total nitrogen in the sweat may be of significance to the question of the relation of nutrition to a tropical environment Its concentration in sweat has been variously reported from 47 to 130 mg % (Talbert, Silvers and Johnson, 1927, Voit, 1933), and the total output per day from 71 mg to 5 28 gms (Benedict, 1906), depending upon ambient temperature and especially upon muscular activity At a temperature of 90°F in New Orleans, Bost and Borgstrom (1926–27) observed an output of 75 mg of nitrogen in the sweat per hour, accounting for some 70% of the difference in output of urinary nitrogen between summer and winter conditions previously observed Bischoff, Maxwell and Hill

(1931) have also reported an inverse relationship between output of sweat nitrogen and of urinary nitrogen Talbert, Silvers and Johnson (1927) noted no relation between the nitrogen in sweat and in urine, and Berry (1915) observed no relation between nitrogen of diet and of sweat However, Cuthbertson and Guthrie (1934) established a clear direct relationship between the daily excretion of sweat nitrogen and the protein content of the diet, which was varied from 70 to 180 gms daily At a room temperature of 15° to 20°C, the output of nitrogen in the sweat ranged from 0 118 to 0 301 gm per m² per day In the Illinois experiments (Mitchell *et al*, 1949), the nitrogen content of sweat averaged about 20 mg %, independent of environmental differences imposed, the hourly output varying from 16 mg under comfortable conditions to 180 mg under hot humid conditions Regardless of their significance to the problem immediately under discussion, this information of the dermal losses of nitrogen in the sweat is of great importance to nitrogen metabolism studies carried out under conditions such that thermal or emotional sweat is produced Metabolism experiments undertaken under sweating conditions *may be seriously vitiated with reference to those elements* and nutrients present in sweat in appreciable quantities, unless dermal losses are measured and utilized in the computation of body balances

The loss of amino acids in the sweat is of immediate interest to the problem of the effect of a tropical climate on nutrition, since these nitrogenous compounds are not metabolites but unchanged products of protein digestion Haugen and Talbert (1928), using the colorimetric method of Folin, report values varying from 1 6 to 4 8 mg of amino acid nitrogen per 100 ml of sweat in 73 experiments upon 23 subjects McSwiney (1934) found an average of 5 0 mg of amino acid nitrogen per 100 ml of sweat for 10 women and an average of 6 6 mg for 14 males These values agree well with the figure of 44 mg of the ten essential amino acids per 100 ml of sweat reported by Hier, Cornbleet and Bergeim (1946), if one may assume an average nitrogen content of about 16% in the amino acid mixture of sweat The latter investigators analyzed 'normal' sweat for the 10 essential amino acids individually by microbiological methods In these experiments the sweat was col-

lected from the entire body except the head by incasing the nude subjects, after a shower bath, in a rubber bag as far as their necks and sweating them in a cabinet for 20 to 30 minutes, during which time 100 to 200 ml of sweat were obtained The following comments on the results secured are interesting

"Our results show that the amino acids secreted in the sweat are independent of the effect of diet or food ingestion since no difference in composition is found in sweat taken from subjects in a fasting state or after eating Furthermore, the level of the amino acids in sweat is independent of the variations in the blood Ingestion of large amounts of amino acids, which causes a marked rise in the blood level, is without effect on the sweat amino acids This must mean that the amino acids do not appear in the sweat merely by filtration from the blood This is further shown by the fact that arginine and histidine are markedly higher and threonine and tyrosine are slightly higher in sweat than in plasma, while the other amino acids studied are present in approximately the same order of magnitude in both fluids The high arginine content of sweat is particularly interesting in view of the findings of Talbert *et al* (1927) that the urea nitrogen of sweat is about four or five times that of blood Arginine may be involved in the formation of this urea by the sweat gland'

Concerning the practical significance of their observations, Hier and associates offer the following comments "The amount of amino acids lost in the sweat is not strikingly significant in the economy of amino acids by the body In our subjects the sweat contained about 0 44 mg per ml of the ten amino acids studied Under average conditions of temperature and humidity, the amount of sweat is about 500 ml per day This would represent a loss of about 220 mg per day of the ten amino acids Even with excessive sweating in warm weather with active work when 3 liters of sweat may be formed, only 1 3 gm of these amino acids would be lost"

It should be noted, however, that the ten essential amino acids constitute only 50 to 60% of the proteins in common foods (Block and Mitchell, 1946), and that the loss of non essential amino acids is just as much a nutritive setback as the loss of essential amino acids Thus, 3 liters of sweat, on the basis of the findings of Hier

et al would contain 2 2 to 2 6 gm of amino acids, and 10 liters, representing an attainable daily sweat volume, would contain 7 3 to 8 6 gm

2 VITAMINS The water-soluble vitamins, in so far as they have been tested for in human sweat, have been found to be present in detectable amounts The great disparity existing among published values of quantitative occurrence is probably traceable to different analytical methods and to different methods of sweat collection The tabulation on page 64 affords a summary of published information

Selecting from this tabulation the analyses that seem to be the most reliable, judged on the basis of methods of assay and sweat collection and agreement with other results, it may be concluded that the following vitamins will generally be found in sweat in a concentration of 20 micrograms or less per 100 ml thiamine, riboflavin, nicotinic acid (total), pantothenic acid, pyridoxine (total), choline, inositol p aminobenzoic acid and pteroylglutamic acid (folic acid) Although the human requirements for all of these vitamins are not known, the concentrations in sweat are so small as to seem insignificant in practical nutrition The concentration of ascorbic acid in sweat is extremely variable and its presence in detectable amounts seems to be sporadic The occurrence of dehydroascorbic acid in sweat, while quite variable in quantity, may be significant in a practical sense

In the experience of most investigators, the concentration of vitamins in sweat is not appreciably, if at all, affected by the dietary intake, with the exception of that of dehydroascorbic acid (Kirch *et al*, 1943), pantothenic acid (Tennent and Silber, 1943) and possibly pyridoxine (Johnson, Hamilton and Mitchell, 1945d) The enormous increases in the thiamine concentration of sweat on dosage reported by Hardt and Still (1941) have not been confirmed by others

The hourly excretions of vitamins in the sweat observed by the Illinois group (Johnson, Spector and their associates), even under conditions inducing sweat secretion of 700 ml per hour or more, were quite inconsiderable compared with known or probable requirements Even the dermal loss of dehydroascorbic acid under these conditions would not exceed about 3 mg per day

Vitamin	Concentration in sweat mcg per 100 ml	Reference
Thiamine	8 to 9	Hardt and Still (1941)
"	3 to 6	Tennent and Silber (1943)
"	0 to 0 1	Slater (1942)
"	0 2 or less	Mickelson and Keys (1943)
"	2 to 3	Mitchell *et al* (1943)
"	15	Cornbleet *et al* (1943)
"	0	Sargent *et al* (1944)
Riboflavin	9 to 2 4	Tennent and Silber (1943)
"	12	Cornbleet *et al* (1943)
"	7 to 1	Mitchell *et al* (1943)
"	0 5 or less	Mickelson and Keys (1943)
"	0	Sargent *et al* (1944)
Nicotinic acid plus metabolites	20[b]	Cornbleet *et al* (1943)
"	100[b]	Mickelson and Keys (1943)
"	4 to 5[b]	Mitchell *et al* (1943)
"	8 to 14	Johnson *et al* (1945b)
Pantothenic acid	11 to 12	Tennent and Silber (1943)
"	30	Cornbleet *et al* (1943)
"	4	Spector *et al* (1945)
Ascorbic acid	500 to 1100	Bernstein (1937)
"	550 to 640[a]	Cornbleet *et al* (1936)
"	100 to 200	Zselyonka *et al* (1937)
"	24 to 57	Wright and MacLenathen (1939)
"	0	Tennent and Silber (1943)
"	50	Mickelson and Keys (1943)
"	0	Sargent *et al* (1944)
"	0 to 15	Kirch *et al* (1943)
"	19	Shields *et al* (1945)
Dehydroascorbic acid	20	Sargent *et al* (1944)
"	60 to 150	Kirch *et al* (1943)
"	70	Shields *et al* (1945)
Pyridoxine + metabolites	7	Johnson *et al* (1945d)
Choline	3 to 15	Johnson *et al* (1945a)
Inositol	21	Johnson *et al* (1945)
Para amino benzoic acid	0 24	Johnson *et al* (1945)
Folic acid	0 26	Johnson *et al* (1945c)

[a]Too high, because sweat was collected in rubber (see Kirch *et al* , 1943)
[b]Exclusive of N[1] methylnicotinamide

3 MINERALS There is a dermal loss of minerals from the body prior to the onset of sweating mainly of sodium, potassium, chloride and sulfate sulfur (Freyberg and Grant, 1937) This loss is incidental to the diffusion of water from the subdermal tissues, the insensible perspiration On the initiation of sweating, the insensible loss of water and minerals presumably stops where the surface of the skin is covered with a film of water

The sensible sweat that supersedes this insensible water (and solute) loss apparently contains all of the minerals found in the blood Besides sodium, potassium, calcium, magnesium, chlorine, sulfur and phosphorus, copper, manganese, iron (Mitchell, Hamilton and Haines, 1949), iodine (Spector *et al*, 1945, and earlier workers) and fluorine (McClure *et al*, 1945) have been identified and concentrations and in some cases, losses per hour, determined The presence of considerable amounts of bromine in sweat was observed but not measured by Spector in the routine of his determinations of iodine in sweat In this discussion we are mainly concerned with those minerals whose losses are of such magnitude as to possess some nutritional significance

The copper and manganese are present in sweat in mere traces, 5 to 6 micrograms per 100 ml

According to Bischoff Maxwell and Hill (1931), phosphorus does not occur in thermal sweat Talbert, Stinchfield and Staff (1933) report variable phosphorus contents in sweat ranging from 0 to 4 8 mg per 100 ml Mitchell *et al* (1949) observed an average of 0 022 mg % of phosphorus in 20 samples of sweat, with individual concentrations ranging from 0 003 to 0 042 mg %, Whitehouse (1931) found only doubtful traces of phosphate in sweat

The magnesium content of sweat is extremely variable (Hopf, 1935) and bears no reasonably constant relation to calcium content although on an average, in the experience of Carpenter and Talbert (1932), the ratio is 4 of calcium to 1 of magnesium, the latter concentrations averaging 1 2 mg % Hopf's average for magnesium in sweat is almost three times this figure, namely, 3 32 mg per cent

Sweat is generally much more dilute in calcium than blood plasma, though the amounts present may be appreciable from the

nutritional point of view Subject to the usual considerable variation, the following concentrations of calcium have been reported 0 3 to 1 5 mg % (Marchionini and Ottenstein, 1931), 5 to 10 mg % (Bryant and Talbert, 1931), 5 8 mg % (Borchardt, 1931), 5 mg % (Carpenter and Talbert, 1932, Talbert, Haugen, Carpenter and Bryant, 1933), 4 6 mg % (Hopf, 1935) and 1 to 4 mg % (Mitchell, Hamilton and Haines, 1949) The concentration seems to decrease as sweating proceeds, and values averaging as high as 12 2 mg of calcium per 100 ml of sweat have been reported by Hopf (1935) for initial collection Mitchell *et al* (1949) found hourly losses of calcium in the sweat over eight-hour periods averaging 5 3 mg under comfortable conditions, and 15 1 mg under hot humid conditions with sweat losses of 700 to 800 gms per hour

The potassium in sweat will generally average 45 to 50 mg % (Talbert, Haugen *et al*, 1933, Borchardt, 1931, Hopf, 1935), though much higher concentrations have been reported for initial sweat specimens Whitehouse (1935) assesses the usual ratio of potassium, as chloride, to sodium chloride in sweat as 1 to 9

The most important mineral component of sweat is sodium chloride and many reports of its quantitative occurrence in sweat generally measured as chloride concentration, have appeared in the literature, extending back into the last century There is little point in citing, or in averaging all reported values Lee (1940) says "The concentrations given by different workers of chloride in heat sweat vary very much In general, they appear to err on the high side, owing probably to evaporation occurring from the sample Later work has indicated that the sweat seldom, if ever, becomes hypertonic as compared with the blood stream, and is usually hypotonic" In view of the variable chloride content of sweat from different areas of the body, the most reliable method of making this determination is to divide the total chloride secreted over the entire body during a definite time, obtained by proper washing procedures, by the net loss in body weight Using this method Lee obtained chloride concentrations in sweat, under varied environmental conditions, ranging from 166 down to 49 mg % According to Bock (1944), sweat sodium varies closely with sweat chloride

The chloride content of sweat, as of many other of its properties, depends upon the rate of sweating, the degree of acclimatization to heat and on inherent characteristics of the individual. Sweat becomes more dilute in chloride with adaptation to hot atmospheres, more concentrated in chloride as the rate of sweating becomes more profuse. "The susceptibility of some individuals to heat cramps no doubt depends in part on the inability of their sweat glands to reduce sodium chloride loss to a low level" (Daly and Dill, 1937). After adaptation, Dill observed the salt concentration of sweat to drop to about 15 milli-equivalents of NaCl per liter in extreme dry heat (1933), and to about the same level (17 milli-equivalents per liter) in humid heat (1937). Johnson, Pitts and Consolazio (1944) have defined these and other conditions determining the salt content of sweat. It is interesting to note the claim of Johnston, Conn, Louis and Steele (1946) that the concentration of chloride in hand sweat represents that of the entire body. Keys (1943b), however, did not find this to be true under his experimental conditions. Ladell (1948) reported a high correlation ($r = +0.73$) between the concentration of chloride in sweat collected from the arm, totally enclosed in a bag, and from the entire body.

While variations in salt intake in the direction of an increase over normal levels does not seem to affect the chloride content of sweat appreciably (Cuthbertson and Guthrie, 1934, Mitchell *et al*, 1943), there can be no doubt that severe restriction of salt intake will reduce the chloride content of sweat to very low levels (Conn *et al*, 1946). This conservation of salt by the sweat glands seems to be mediated by the same endocrine mechanism that favors salt conservation by the kidney, i.e., desoxycorticosterone, since Bock (1944) observed that the administration of potent extracts of the adrenal cortex of cattle to men fully acclimatized to heat decreased the level of sodium and chloride in the sweat. The association of negative nitrogen balance with low salt intake and its correction by an increased salt intake in acclimatized men has already been noted (Conn and Johnston, 1945) and is probably attributable to the same endocrine mechanism.

The dermal loss of iodine in man has been recognized since iodine balances were first performed by von Fellenberg in 1926

Spector, Mitchell and Hamilton (1945) studied the concentration of iodine in sweat and the hourly loss of iodine through the skin under different environmental conditions and with and without dosage of the subjects with potassium iodide. The results obtained can be briefly summarized as follows.

The concentration of iodine in sweat averaged about 1 microgram per 100 ml., increasing to 3.2 mcg. after a single dose of 2 mg. of KI. The hourly loss of iodine through the skin during eight-hour exposures to controlled environmental conditions varied from 1 to 5 mcg., and was not consistently correlated with the environmental conditions or with the rate of sweating.

The absorption and excretion of iodine by normal human subjects has been investigated more recently by Nelson and coworkers (1947). In their experience the concentration of iodine in sweat is related to that in blood plasma: roughly, the concentration of sweat iodine is about one-third that of plasma iodine.

Vannotti and Delachaux (1949) in their book on iron metabolism mention (page 29) the important part played by the sweat glands in iron excretion, citing in particular the report of Chevallier (1923). However, Chevallier does not, in the publication referred to, offer any evidential support for his thesis that the sweat glands are important organs of elimination of iron. On the other hand, Johnston and Hagan (1949) observed only minimal amounts of iron in the sweat collected from five women, averaging 0.04 mg. per liter.[3] In this connection, reference may be made to the occurrence of stainable iron deposits in the apocrine, but not the eccrine, glands of human subjects (Bunting, Wislocki and Dempsey, 1948).[3a]

Mitchell, Hamilton and Haines (1949) have reported evidence on this problem. Taking the proper precautions to avoid iron contamination, and using 4 young men as subjects, it was found that sweat averages about 1.8 mg. of iron per liter, using the washing

[3] In a later publication from the same laboratory (*J. Nutrition* 42: 285–296, 1950) *a more complete collection of sweat from 4 women subjects indicated* a six fold increase in iron concentration: 0.24 mg. per liter, and even in these experiments sweat was not collected from the scalp as it was in the Illinois investigations.

[3a] Confirming earlier work by H. Homma (*Bull. Johns Hopkins Hospital*, 67: 365–371, 1926).

method to secure the dermal loss of iron from the entire body, and taking the net loss in body weight as measuring the sweat loss For individual tests, the variations were not extreme, the coefficient of variation of 27 weekly averages being 28 1%

The relatively large amounts of iron found in sweat by Mitchell, Hamilton and Haines (1949) could hardly have been due to contamination, because of the precautions taken to avoid it The fact that the iron content of sweat was not demonstrably affected by the rate of sweating, is objective evidence that the measures taken were successful For sweat produced at rates of less than 200 ml per hour, the iron content averaged 1 91 mg per liter, and for sweat produced at rates of 200 to 900 ml per hour, the iron content averaged 1 64 mg per liter The t value of the difference (Fisher, 1944) is 1 464, and the probability that a random combination of the uncontrolled factors in the experiment could have produced a mean difference as large or larger than that observed is 0 17 This probability is too large to be disregarded

The hourly loss of iron under different environmental conditions is given in Table I, each figure being the average of four experimental subjects over five experimental days each

TABLE I

The Effect of Environment on the Hourly Dermal Loss of Iron

Temperature °F	Relative humidity per cent	Insensible loss in body weight gms per hour	Hourly dermal loss of iron mg
101	69	814	1 77
100	70	688	0 80
101	66	584	0 90
90	94	297	0 95
90	66	134	0 25
85	50	113	0 21
85	49	103	0 33
85	50	87	0 17

These hourly losses of iron through the skin are considerable compared to the daily metabolism of 10 or 15 mg They throw a rather devastating light upon the "new theory of iron metabo-

lism," well epitomized by Johnston (1948) According to this theory, the body finds it difficult to eliminate what iron is absorbed from the food, either in the feces or in the urine The body iron is thus used over and over again, and is conserved to a very much greater extent than has been observed for any other mineral However, the theory neglects entirely the dermal excretion of iron, which may evidently be considerable Its evidence that excretion through the intestinal mucosa is negligible is not convincing, and its presumption that the body absorbs from the gastro intestinal tract only as much iron as it needs is contrary to the known ability of the liver, and possibly other tissues, to store iron, while the mechanism proposed for the blocking of iron absorption in the intestinal mucosa, while ingenious, rests upon a tenuous basis (Granick, 1946) *

TEMPERATURE OF FOOD AND DRINK

The temperature at which food and beverages are consumed might be expected to influence the digestive processes Eberhard (1940) has reported that ice water and ice cream retard the

*Since the above statement was made Stewart Snowman Yule and Whipple (*Proc Soc Exper Biol & Med*, 73 473–475 1950) have reported failure to demonstrate a dermal excretion of iron in the dog However Adams Leslie and Levin (*Ibid* 74 46–48 1950) demonstrated an excretion of iron in filtered arm sweat in 10 of 15 subjects in amounts ranging up to 2 15 mcg per cc Untreated cell rich sweat contained iron in all samples in amounts ranging from 0 78 to 19 5 mcg per cc Iron contamination from the rubber gloves used in sweat collection can be ruled out (personal communication from Dr Adams) The authors state From the data obtained it is concluded that the loss of iron in human sweat is negligible Loss of iron from desquamation of the epithelium may be considerable although no quantitative estimates were made The first conclusion is not borne out by their data especially in view of the variable occurrence of iron in sweat from different regions of the body In the Illinois experiments above discussed the iron content of spot samples of undiluted sweat varied from 10 to 177 mcg per 100 cc The loss of iron by desquamation was amply demonstrated by Adams *et al* Furthermore, continuous desquamation of mucosal cells from the intestinal tract demonstrated by Lebland and Stevens (*Anat Rec* 100 357–377 1948) would presumably remove the ferritin granules deposited in the mucosal cells (Granick *J Biol Chem*, 164 737–746 1946)

emptying time of the stomach by 30 to 60 minutes, while hot coffee has no effect Cold drinks, such as may be consumed as refreshments in the tropics, also affect heart action as revealed by inverted T waves, and the author suggests a possible correlation of this effect with so called "acute-indigestion" Gershon-Cohen and co-workers (1940) observed that cold meals seem to speed up gastric evacuation, while depressing gastric secretion during the initial stages of digestion "Summer diarrhea might be due partly to ice-cold drinks which effect too rapid gastric evacuation of gastric contents not effectively prepared for the intestines because of the depression in gastric secretions' The reason for the apparent discrepancy between the results of these two studies needs elucidation

SOLAR RADIATION AND AIR MOTION

In the construction of weather chambers for environmental studies on man, two components of weather wind and solar radiation, are most difficult to duplicate as they occur outdoors Variable winds of variable intensity are characteristic of outdoor life and are difficult to duplicate indoors throughout natural ranges The spectral qualities of sunlight have never been exactly duplicated artificially The effect of air motion and of solar radiation on the heat economy of men under tropical conditions will not be considered in any detail here, the subject is introduced merely to complete the discussion of the physiological effects of a tropical climate

Winslow, Gagge and Herrington (1939) have found that the cooling effect of air movement varies with the square root of the velocity Significant wind effects on evaporation from the skin through dry fabrics is found only at permeabilities above 30, greater than that of some important Army fabrics (Fourt and Harris, 1944) "Until permeability rises far above 30, fabric thickness is probably the dominant influence on physiologic efficiency in cooling" Gold (1935) has compiled a table of sensations associated with different wind velocities under different dry and wet bulb temperatures that should correlate with Houghton and Yaglou's effective temperature nomogram

The thermal qualities of solar radiation have been referred to above An analysis of this heat load has been presented by Blum (1945b) and seems to be equivalent to 4 kg cals per min, two or three times the resting metabolism of an average man One important function of clothing in a tropic environment is to cause the reflection from the body of much, or most, of this heat load Oppel and Hardy (1937) showed that, of the rays impinging on the skin, the more penetrating they are the less sensitive is the subject to them, and that dermal pigment plays only a small role in the thermal exchange between environment and man However, in this section of the report, we will be mainly concerned with the actinic effects of the solar rays, producing biochemical changes in the body and biochemical damage In this connection reference should be made to the excellent review of Blum (1945a) on the physiological effects of sunlight on man The physiological activity of cosmic rays and of cosmic radiocarbon (Grosse and Libby, 1947) may later be shown to be of importance, especially at high altitudes

Sunburn is a lesion induced by exposure to intense sunlight Its military aspects have been well presented by Blum (1943), from whom the following citation is taken "There is evidence that dietary factors may affect the sensitivity to sunburn, but to date this has not received adequate investigation" The possible non nutritional protective measures against sunburn have been evaluated by Blum, Eicher and Terus (1946) The presence of sweat on the skin is of importance in this connection, since a sweat film of 1 mm thickness transmits only about 27% of solar radiation effective in preventing sunburn according to a report by Crew and Whittle (1938) On the supposition that pellagra may be a result of tryptophan (or protein) deficiency, based on some experiments by Chick and Hume (1920) on monkeys, Dawbarn (1924) attempted to induce light-sensitivity in mice by placing them upon a tryptophan deficient diet, but without success

The consumption of certain plants by farm animals, such as buckwheat, and plants belonging to the genus Hypericum may cause an abnormal sensitivity to light The excessive consumption of chlorophyll containing plants may induce a photo sensitivity by the production of phylloerythrin in the digestive tract (see

Blum, 1941) The dermatitis of pellagra in man is exacerbated by sunlight and by heat (Smith and Ruffin, 1937), while there is some suggestion that nicotinamide, the absence of which from the diet is responsible for many of the lesions of pellagra, possesses a light-protective-action as yet unexplained (Kuhnau, 1939)

Ultraviolet radiation of wave lengths that produce sunburn will cause injury to the eye the cornea and conjunctiva (photophthalmia), the retina (scotoma), and possibly the lens (cataract) (Blum, 1945a) According to Jolliffe (1943) from experiments on humans, 'light, within the degree used in these studies, is without great significance in the production of corneal vascularity " In the rat, intense light from incandescent lamps does not modify appreciably the riboflavin content of the retina (Bessey and Lowry, 1944), nor modify the eye changes induced by riboflavin deficiency (Lowry and Bessey, 1945) Light exposure in the human does not seem to modify appreciably the carotene requirement (Booher and Callison, 1939), though vitamin A is intimately involved in the mechanics of rod vision A crude estimate is given by Friedenwald *et al* (1948) of the ultraviolet spectral sensitivity curves for the corneal epithelium of the rat in respect to mitosis inhibition, nuclear fragmentation and loss of tissue cohesion

THE EFFECT OF HEAT ON NUTRIENT REQUIREMENTS ANIMAL EXPERIMENTS

Readers of this report may be interested in a dissertation by Brobeck (1948), based upon experiments with laboratory animals, that 'animals eat to keep warm, and stop eating to prevent hyperthermia " According to Brobeck, food intake appears to be controlled as if it is a mechanism of temperature regulation

1 VITAMINS Mills has performed many experiments on growing rats to determine the relative vitamin requirements in a cool room (65°–68°F) and in a hot room (91°F , 60% relative humidity) The procedure was quite similar in all experiments A series of diets is prepared that is presumably adequate in all respects except for the vitamin under study, which is incorporated in the

diets in graded doses The diets are then fed *ad libitum* to groups of four to six rats, both in the cool room and in the hot room The requirement in each environment is taken to be the smallest concentration of the vitamin that has induced the best growth, or that has averted symptoms of avitaminosis With this technic Mills has concluded that the requirements for thiamine (1941), choline (1942) and vitamin K (Mills *et al*, 1944) are sharply increased in a tropical, as compared with a temperate, environment, but that the requirements for riboflavin, pyridoxine, pantothenic acid, p aminobenzoic acid and inositol are not affected by the environment (1943a) The indicated increased requirements for thiamine, but not for choline, in a tropical environment, and the failure to demonstrate differences in requirements for the other B vitamins were later confirmed on chicks (Mills *et al*, 1947) The heightened thiamine and choline requirements in tropical heat were also confirmed for rats (1943b), having particular regard to the possible destruction of thiamine in diets kept in a hot room

The consistency with which Mills has been able to repeat his thiamine findings (see also Mills, 1948) is impressive, but the interpretation of his data is none the-less difficult Wide differences occurred in the intake of food in the two environments, greater amounts being consumed in the cold, while within either room, the gains in body weight secured generally paralleled the food intake The *ad libitum* feeding technic, when used to assess nutrient requirements, tacitly implies that the experimental animals will consume food in proportion to its nutritive adequacy This proposition has never been proved With reference to thiamine in particular, Waterman and Ammerman showed with rats (1935a) and with pigeons (1935b), that increasing doses of the vitamin will stimulate growth, probably merely by stimulating food consumption, far beyond doses that would represent requirements 160 mcg per day for rats and pigeons was still inadequate for maximum growth, though far in excess of any reasonable estimate of the thiamine requirement Interpretation of the Mills' experiments is difficult also because the data have not generally been subjected to an adequate statistical treatment, particularly incidence ratios of deficiency symptoms, and where statistical measures of the operation of uncontrolled factors in the experi

ments have been given, as standard errors or other measures of variation, little use has been made of them in the interpretation of the data. The possibility has not been considered in the interpretation of incidence ratios that a tropical environment may merely visualize latent symptoms of deficiency, as light and heat serve to visualize dermal malnutrition in pellagrins.

It is difficult to conceive why the requirements for vitamins per unit of food consumed should be modified by environmental temperature, especially as markedly as Mills' evidence indicates for thiamine, since the function of thiamine in the body, in so far as it is known, relates to the metabolism of food. Possibly a tropical environment will raise the body temperature of the rat, speed up the metabolic reactions including those involving the destruction of thiamine and thus raise the thiamine requirement per unit of food to be metabolized. Attempts to confirm Mills' results on rats in other laboratories have not been entirely successful, though the experimental procedures used have not always been above criticism.

Sarett and Perlzweig (1943) approached the problem by studying the metabolism of the B vitamins in growing rats maintained at 75°F or 91°F. Growth, urinary excretion (except for thiamine) and tissue storage in the two environments, of thiamine, riboflavin, pantothenic acid and nicotinic acid were measured on two diets, one containing slightly above minimum requirements of the vitamins and the other containing excessive concentrations. The food intakes of the groups at the lower temperature were restricted to those of the corresponding groups at 91°F, which were fed *ad libitum*. This procedure penalized the rats kept at 75°F because of their greater caloric requirements. The urinary excretion of riboflavin, pantothenic acid and nicotinic acid averaged somewhat higher on both levels of vitamins in the hot environment, but the statistical significance of the differences between pair mates was not evaluated. At the end of 22 to 25 days, the content of the several vitamins was determined in liver and in carcass. At the higher level of vitamin supply, the retention averaged greater for all vitamins, except for nicotinic acid storage in the liver, in the hot environment, but at the lower level of vitamin supply, the reverse was generally true. The results cannot be readily inter-

preted in terms of requirements in the two environments, mainly because the obvious interpretations of the results on the two levels of vitamin supply are contradictory. Williams, Eppright, Cunningham and Mills (1944), using *ad libitum* feeding were not able to detect differences in vitamin storages in rats at low and high room temperatures on diets containing adequate concentrations of the B vitamins, but higher dietary concentrations of thiamine and choline were offered to some of the rats in the tropical environment.

Robinson (1943) studied the thiamine requirements of growing rats at different environmental temperatures by growth and food utilization studies and by the output of pyruvate in the urine. The paired-feeding method was used throughout, but only for rats in the same environment and undergoing the same test on graded doses of thiamine. In determining the thiamine requirement at different temperatures the most sensitive method was that involving determination of the minimum amount of thiamine required to prevent an increased excretion of pyruvate in the urine. Robinson's results demonstrated a higher thiamine requirement at the higher temperatures, ranging from 0.7 mcg. per gm. of food at 15°C. to between 2.0 and 2.4 mcg. per gm. of food at 35°C.

Failure to appreciate the fact that thiamine requirements and probably the requirements of some other B vitamins, are related to the amount of food metabolized, and therefore the food intake of the experimental animal, has introduced confusion into this problem. Kline, Friedman and Nelson (1945), administering thiamine supplements in constant amounts and allowing food *ad libitum,* concluded that thiamine requirement in the rat is decreased with increase in environmental temperature and that this decrease is related to a decrease in caloric requirement. The thiamine: food ratio was always more favorable for the high temperature rats, so that at the low levels of thiamine supply, they survived longer after a curative dose, or grew better, than the low-temperature rats. This experiment confirms what Amantea (1933) proved many years ago, i.e., that there is a relationship between the caloric intake of animals and the vitamin B_1 requirement.

The experiments of Edison, Silber and Tennent (1945) are subject to the same limitation of interpretation as those of Kline *et al* in so far as they administered thiamine dosages in constant amount irrespective of the caloric intake Most of the experiments reported were carried out with diets containing 20 mcg or more of thiamine per rat per day On such rations there was no significant difference in the concentration of thiamine in the liver, whether feeding was *ad libitum* or equalized, or between tropical and temperate rats The conclusion Thiamine requirements for the growth of rats in a tropical environment (90°F and 70% relative humidity) are not greater and may be less than in temperate conditions (72°F and 50% relative humidity)," must rest upon those experiments carried out at lower levels of thiamine intake When the intake was reduced to 2 mcg daily or less, the weight loss gradient was said to be much more gradual in the tropics than in temperate conditions, although the weight curves do not support this conclusion solidly In any case, differences in activity and metabolic rates in the two climates complicate the interpretation of weight curves The greater incidence of polyneuritis among rats in the temperate environment fed *ad libitum* clearly was due to their smaller thiamine to calorie ratio The data cannot be considered to support the conclusion above stated

Ferrero (1940) has reported that massive doses of nicotinamide (200 mg) given to rabbits before heat treatment increases their resistance to heat and raises the tolerable temperature Such doses possess no nutritional significance [5]

Kurokawa (1941a and b) has reported that avitaminosis A can be induced more speedily in rats in a hot environment than in a cool one and that with rabbits, higher temperatures can be tolerated after massive doses of vitamin A The reviewers have not had access to these reports Salvatore (1949) noted an in

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crease in body weight of rats on a vitamin A deficient diet, but not on a complete diet, lasting three to 10 days, when the room temperature was changed from 20° to 32°C What change in food intake may have occurred simultaneously is not indicated in the abstract available to the authors of this Brazilian work

The distressing variation exhibited by different rats in assays for vitamin D, has led investigators to study all possible factors with reference to the selection of test animals and to the environment that might be brought under better control From a statistical study of their experiences with this assay Tourtellotte and Bacon (1935) suggested that room temperature may be a factor, since their results indicated, though not very strongly, that rats are more sensitive to rickets at room temperatures of 80°F or above Two years later, Guerrant, Dutcher and Crowthers (1937) subjected this suggestion to systematic study Comparable experiments were performed at 73°, 84° and 100°F, using a uniform rachitogenic diet and carefully selected test animals The severity of rickets was measured by x-ray examination of the bones, the line test, the ash content of the bones, and the calcium and inorganic phosphorus in the blood serum The mass of data obtained led the authors to believe 'that environmental temperature is not an important consideration in either the production or the cure of rickets in the rat"

However, variable food intakes—lesser food consumption in the hotter rooms—complicate the interpretation of the data, especially since the authors admit 'In our regular vitamin D assays, where all animals are maintained at a comparable temperature, those animals which make the greatest increase in body weight [and presumably consume the greatest amount of food] invariably show the highest degree of rickets' This confirms the recorded experience of Watkins and Mitchell (1936) When on the rachitogenic diet, the rats in the warmer rooms, consuming less food, showed slightly severer rickets as judged by the line test, but not by the other criteria, which may have been less sensitive It is probable, therefore, that if the rats in the warmer rooms had consumed as much food as those in the cool room they would have exhibited a more marked difference in the severity of rickets at the end of 21 days of feeding

The results of Guerrant *et al* may, therefore, be considered to support the presumption that the sensitivity of rats to rickets, and probably their requirements of vitamin D, are enhanced in a hot environment

There is some slight suggestion that high temperatures, in so far as they induce hyperpyrexia, may increase the requirement for ascorbic acid, if one may so interpret decreases in the content of the vitamin in the tissues of animals subjected to artificial fever (Martini and Torda, 1937, Zook and Sharpless, 1938) Haas (1939) from experiments on rats, guinea pigs and rabbits, concluded that ascorbic acid curbs the increase in body temperature induced by drugs and by high external temperatures

2 PROTEIN Mills (1944b), having previously shown to his own satisfaction that subsistence in a tropical climate raises sharply the required concentration in the diet of thiamine and choline, felt some concern about the matter of protein requirements This concern arose from the fact that food high in the B-vitamins are generally high in protein, and that high protein foods are often eschewed in hot weather and climates because of their high heating effect, commonly referred to as their specific dynamic action Hence, he carried out an experiment on growing rats, using the technic already described to determine the protein requirements for growth in cool and hot environments The protein used was casein, without and then with a cystine supplement, and the dietary levels tested ranged from 6 to 36%, with 4 rats to a diet group

The average data reported are quite irregular for the rats in the cold room They are interpreted by Mills to mean that, for unsupplemented casein the growing rat requires a greater concentration in the diet in the hot than in the cold environment, but for the supplemented casein, no difference in requirement exists This anomalous conclusion needs much better evidential support than Mills' experimental data afford before any credence need be given to it The protein requirement of growing animals is not directly related to the amount of food to be metabolized, as are, in all probability, the B-vitamin requirements, rather it is related to the gain in weight and the size of rat When Mills' data for the first three weeks of feeding are analyzed, it will be found that the

relationship between gain in weight and protein intake follows the same curve in both hot and cold rooms

THE EFFECT OF HEAT ON NUTRIENT REQUIREMENTS
EXPERIMENTS ON HUMAN SUBJECTS

1 ENERGY A tropical environment seems to have no consistent effect upon the basal requirement of energy (Mason, 1940, Spealman, Yamamato, Bixby and Newton, 1948), and where effects have been noted they are not considerable, being of the order of 10 to 15%, and generally in the nature of a depression of the rate characteristic of the temperate climate Muscular activity is reduced, especially the severer forms On the other hand, the lighter weight clothing worn in the tropics permits the performance of many types of activity with a smaller expenditure of energy per unit of work (Gray, Consolazio and Kark, 1947) Appetite may be adversely affected in the tropics, at least until acclimatization is attained, and the consumption of adequate calories may be dependent more than usual upon the appetite appeal and tastiness of the food offered The importance of an adequate caloric intake for troops in the field under conditions of severe work in a tropical environment has been emphasized in many writings by qualified observers, among which the report of Brown and McCreary (1943) may be cited here In another report, Taylor (1946) says, speaking of diet and fluids "Hot weather presents no peculiar problems other than taste, custom and supply Palatability is essential to combat the prevalent anorexia as assurance for good nutrition"

Van Veen (1942) calls attention to the low fat consumption in Java, 5 to 12 gms per day per adult of 50 kgm consuming 2600 calories, even in the most prosperous section of the population He is of the opinion that one should not speak about a "requirement-norm" for fat, but only of a 'habit norm" The danger of a deficiency of linoleic acid is minimized, should such a requirement be established for man, since the fats from rice and maize, coconut and peanut, probably contain a sufficiency of unsaturated fatty acids found to be essential for the rat

2 WATER AND SALT The requirements for water and salt are markedly affected by a tropical environment and are so interdependent that they must be considered together The greater the output of water in the sweat the greater the requirements for both water and salt, while the greater the intake of salt the greater the requirement of water

It is obvious that the loss of water during sweating will increase the water requirement by a like amount minus the compensatory decrease in urinary water with any correction, one way or the other, dependent upon changes in the evaporation of water from the respiratory passages These latter factors are probably relatively inconsiderable under conditions inducing severe sweating The experience of trained observers of men working in a tropical environment, both in the laboratory and in the field, emphasizes the importance of replacing these water losses continuously

Pitts, Johnson and Consolazio (1944) express their well founded conclusion as follows The best performance of fully acclimatized young men on a good daily diet, performing intermittent hard work in the heat, is achieved by replacing hour by hour the water lost in sweat Any amount of water considerably less than this leads in a matter of hours to serious inefficiency and eventually to exhaustion"

The need for water may actually outstrip the thirst for water "It should be emphasized that during work men never voluntarily drink as much water as they sweat, even though this is advantageous for maintaining heat balance, but usually drink at a rate approximating about two thirds of the water loss in sweat Although cool water is more palatable, water at any temperature up to 100°F is equally beneficial The deficit is made up in the rest periods following the day's work' (Pitts *et al*, 1944)

The experience of the Armored Medical Research Laboratory at Fort Knox, Kentucky, is described by Nelson and Bean (1942) in the following words " for the mild desert conditions (maximum temperature around 110°F) limitation of water to four quarts a day resulted within a period of days in operational inefficiency ' And further " water consumption was substantially the same whether water was taken only at meal times or taken when thirsty Those who delayed drinking until meal time experi-

enced considerable discomfort, without any apparent advantage in water economy or physical well being Drinking in small amounts when thirsty would seem to be the ideal practice "

The additional amount of water required in a tropical over a temperate environment will vary widely with environmental con ditions, with muscular activity and from man to man In a report to the Food and Nutrition Board of the National Research Council Hastings and Guest (1944) state that while 4 liters of water per day may suffice for men at light work at a maximum temperature of 95°F, for men at heavy work at a temperature of 113°F the requirement may be raised to 13 liters

The need for extra water during work in the tropics is much more urgent than the need for extra salt Replacement of salt losses hour by hour, unlike the replacement of water, has no demonstrable advantage (Pitts *et al*, 1944) The salt loss can be replaced just as well at meal time Taylor and co workers at the University of Minnesota (1943) studied the effects of three levels of salt intake on the cardiovascular functions of 49 unacclimatized men at work and at rest during exposure to hot dry conditions water being allowed *ad libitum* The salt was administered with the meals, and the exposure periods were of short duration i e two to 3 5 days each With day temperatures of 120°F dry bulb and 85°F wet bulb, and night temperatures of 85° to 95°F dry bulb and 65° to 75°F wet bulb, daily intakes of 4 to 8 gms of salt were found to be inadequate, being associated with higher pulse rates and rectal temperatures, poorer postural cardiovascular ad justment, greater loss in body weight, and a salt deficit of 13 gms in 3 days On the other hand, a high intake of salt 28 to 32 gms daily, showed no advantages over a moderate intake of 13 to 17 gms daily, even though the sweat produced amounted to 5 to 8 liters daily These experiments, it should be remembered were carried out on unacclimatized men in observational periods of only two to eight days

According to Conn and Johnston (1944), there exists in fully acclimatized men an adaptive mechanism whereby salt concen tration of the sweat is [illegible] consistently diminished when the need for salt [illegible] ecomes acute' Their ex periment[illegible] balance [illegible] acclimatized men over

periods of 50 to 80 days performing hard work (4100 to 4600 cals per day) in a tropical environment (85°F and 85% relative humidity), and producing 5 to 9 liters of sweat daily Under these conditions it was possible to maintain salt equilibrium on a total salt intake of 6 gms daily One subject was able to establish equilibrium on less than 3 gms of salt daily In conclusion the authors of this interesting report state· "We believe that these studies indicate that salt supplements are not needed and may actually be deleterious, that the average diet containing 10–15 gms of NaCl affords adequate protection against salt depletion"

Certainly there seems to be a wide margin between the usual intake of salt and the day's requirements under moderate environmental conditions These requirements have been assessed at 5 gms daily by Hastings and Guest (1944) and 2 gms daily or less by Falconer and Lyall (1937)

If, and when, it becomes necessary to supply salt in forms other than food, the use of salt tablets may be resorted to Consolazio, Pecora and Tusing (1947) have devised a slow-dissolving non-irritating salt tablet for use in hot environments However, the trend in modern research and thinking is against the need, or advisability, of administering salt to men working in the heat either in tablet form or as salinized drinking water, except possibly in the case of unacclimatized men The modern view is well stated by Pitts, Johnson and Consolazio (1944) as follows "It would appear from the present experiments that in the case of well acclimatized young men, whose daily diet is adequate, the best performance of intermittent work in the heat is to be achieved by replacing water loss hour by hour and salt loss meal by meal"

3 PROTEIN Whether the inhabitants of tropical or sub-tropical regions voluntarily select diets lower in protein than inhabitants of temperate regions seems to be a controversial question It is difficult to dissociate diet selections based upon economic status and availability of food supplies from selections based upon physiological motivations Perhaps as clear an expression as has been secured of physiological factors, relatively uncomplicated by economic factors, is obtained by studying the diet selections of college students in temperate and sub-tropical sections of the

United States Denis and Borgstrom (1924) studied the urinary nitrogen output of college students in New Orleans and found the indicated protein intake to be low, 74 gms daily, and to be lower in the summer months than in the winter months The later report by Borgstrom and Bost (1926-27) further confirmed the presumption that climatic conditions affect the voluntary intake of protein* However, Youngburg and Finch (1926) found as low an output of nitrogen in the urine in college students at Buffalo as had been observed previously in New Orleans, with no observable tendency for the urinary nitrogen to decrease during the summer months Apparently, the question whether climatic factors *per se* modify the protein appetite of man cannot be answered except on the basis of more extensive statistical surveys

Caspari and Schilling (1920) followed the nitrogen metabolism of two individuals at rest and at work in Berlin, and during periods spent on the west coast of Africa The diets consumed in both localities were quite similar, containing about 1 1 gms of nitrogen and 33 cals per kgm body weight per day The subjects were generally in negative nitrogen balance in all tests, apparently due to an inadequate caloric intake, but the balances in the tropical regions (determined with due regard to dermal losses) are not distinguishable from those in the temperate regions Also, the intestinal utilization of nitrogen, fat and energy was not significantly different in the two climates The authors conclude that the body uses food in the tropics as efficiently as elsewhere, and, in particular, that nitrogen balance can be maintained as easily in Africa as under similar dietary conditions in Berlin

In experiments (1949) only partially published, Mitchell, Hamilton and Haines studied the nitrogen metabolism of four men under comfortable and under hot-humid conditions, on different levels of dietary nitrogen, approximately 13, 15 to 16, and 21 to 23 gms daily The collection periods were five days in length, on each of which the subjects were confined to the experimental rooms for eight hours The experiments lasted from late January through May At the lowest levels of protein intake, the sweat

*However Bost and Borgstrom (1926-27) noted that nitrogen in the sweat could account for 70% of the difference in urinary nitrogen between summer and winter months

nitrogen amounted to less than 1% of the intake in the comfortable environment and to 10 to 11% of the intake in the hot-humid environment The nitrogen balances for all subjects were less under the latter conditions than under the former by about 1 gm of nitrogen daily At the higher levels of intake, however, no consistent differences in nitrogen balance were noted in the two environments

If a condition of pyrexia is induced by residence in a tropical environment, an increase in the endogenous catabolism of body protein, as revealed by an increased output of creatinine in the urine, is to be expected Such an effect of elevated body temperature on creatinine output in the urine was clearly shown by Myers and Volovic (1913) in experiments on rabbits in which hyperthermia was induced artificially by infection Both Shaffer (1908) and McClure (1918) have observed the same phenomenon in acute febrile conditions in humans, together with creatinuria, indicating an accelerated endogenous catabolism of nitrogen According to Graham and Poulton (1912) a febrile condition may or may not increase the total protein metabolism depending upon the availability of other sources of food energy

While it is probable that a tropical climate may increase the endogenous catabolism of protein if it induces an elevation of body temperature there are no good grounds for believing that the protein requirements of men will be appreciably altered in the tropics particularly after acclimatization

4 VITAMINS The concentration of vitamins in sweat (see above) is not sufficiently great to modify appreciably the vitamin requirements of man in a sweating environment, even under extreme conditions of sweating, with the possible exception of ascorbic acid However, the observations of Fox (1940), to be cited at more length below, do not reveal any grounds for believing that the ascorbic acid requirements of man are increased under extreme sweating

Some suggestions have appeared in the literature that a warm environment modifies the vitamin requirements of man Holt (1943) has observed a greater urinary excretion of thiamine in hot weather and the reverse in cool weather He interprets this parallelism between environmental temperature and urinary thia-

mine output as an indication of a lessened requirement for the vitamin in a hot climate and hence a greater spill over in the urine However, this parallelism may not be so easily interpret able In the Division of Animal Nutrition of the University of Illinois, in similar experiments on pigs in a controlled environ ment, the relative thiamine output in the urine in a hot as com pared with a cold environment may be different on a high as com pared with a low thiamine intake On a low intake we checked the observations of Holt on man, but on a high intake, the urinary thiamine was very much less in the hot than in the cold (un published experiments) The ratio of thiamine to dietary calories was kept the same in both environments A decreased excretion of thiamine in the urine in a hot as compared with a cool environ ment was also reported for rabbits by Iwamoto (1941)

Williams, Mason, Wilder and Smith (1940) in their studies of the thiamine requirements of psychopathic patients believed that they observed a climatological factor A diet restricted to 0 15 mg of thiamine was tolerated by four subjects for 147 days during the summer months before deficiency symptoms developed A similar diet given to four other subjects in the winter months could be tolerated for only 88 days Since symptoms of thiamine deficiency developed earlier in the winter months, there is a suggestion that the requirement is greater in the winter than in the summer How ever, there is no assurance in these experiments that the body stores of thiamine were the same in the subjects observed in the summer months as in the subjects observed in the winter months, that body stores of thiamine were an important determinant in the outcome of the experiments is indicated by the long deferment of deficiency symptoms on a grossly inadequate intake

An elevated body temperature such as may be induced by work in the tropics, has been observed to lower the blood plasma concentration of ascorbic acid in man by Daum Boyd and Paul (1939) and to decrease the urinary output (see also Zook and Sharpless, 1938), Hausberger and Nevenschwander-Lemmer (1939) observed a more rapid disappearance from the blood of injected ascorbic acid in patients with fever than in normal per- sons, Zook and Sharpless (1938) and Falke (1939) have pre- sented evidence of much the same significance, though Craig *et al*

(1946) were not able to demonstrate an effect of fever on the level of ascorbic acid in the blood of patients in whom fever was induced by physical means or by the use of chemotherapeutic agents

However indicative such observation of the effect of fever on ascorbic acid requirements of man may be, the reviewers have found no direct evidence that the requirements are raised in the *tropics even under conditions of severe work* The negative evidence obtained by Fox (1940), experimenting with large groups of native laborers in a Witwatersrand gold mine in South Africa, is especially significant Having concluded from a critical review of the literature that 'A net daily *intake of 15 mg appears to be* all that is required, not only to protect the average individual from scurvy, but also to maintain him in good health," Fox (1940) carried out an extensive study on two groups of 950 mine laborers each during a period of seven months 'The groups were chosen so as to be as comparable as possible in respect to tribe, age, physical condition and occupation One group remained on the usual mine diet, which was estimated to contain 12 to 25 mgm ascorbic acid, while in the other, an additional daily ration of 40 mgm vitamin C was administered in the form of orange juice concentrate" The low order of the reserves of ascorbic acid in these native miners is revealed by low plasma values (less than 0 3 mg % and generally less than 0 2 mg %) and by the results of a saturation test Twelve cases of scurvy occurred in the control group during the course of the experiment and one mild case in the supplemented group

"Otherwise, *no significant difference could be detected between* the two groups Thus the change in weight was almost identical and there was no evidence forthcoming that the general health, physical efficiency, condition of the gums or resistance to infection had been improved" The examination of the gums of the experimental subjects was carried out by a dental surgeon and the physical efficiency tests by persons trained in physical education The latter tests aimed at measuring the main components of physical efficiency, namely strength, skill and endurance, were consistently negative

Although the temperature and humidity of these Witwatersrand

gold mines are not, strange to say, given in Fox's article, from other articles (Dreosti, 1935–36 Cluver, 1932) it is evident that the temperatures and humidities are severe, about 95°F and close to saturation The experiments of Fox may, therefore, be interpreted to mean that the ascorbic acid requirement of men working in hot humid surroundings is not elevated appreciably, and is in fact of a surprisingly low order of magnitude

5 Minerals The only evidence relating to a possible effect of a hot environment on the mineral (other than common salt) requirements of man, of which the reviewers are aware, were secured in experiments by Mitchell Hamilton and Haines at the University of Illinois (1949) Such an effect would be expected largely on the basis of mineral losses in the sweat, which have been discussed above In these experiments it was shown that the iodine, calcium and iron losses in the sweat were of such magnitude as to modify requirements appreciably provided compensatory conservation of these elements by other excretory channels did not occur

With reference to iodine, balance experiments on four subjects showed that conservation of iodine by the kidneys compensated for dermal losses so that the iodine balance was not less in a hot humid than in a comfortable environment (see Spector *et al*, 1945, for most of these data)

For calcium, both at a low daily intake of about 715 mg and at a high intake of about 1670 mg, compensatory factors did not operate effectively, and the calcium balance in the hot humid environment was less than that in the comfortable environment by 100 mg daily at the low level of intake and by over 400 mg at the high level These statements relate to average balances for three or four men The individual balances were somewhat irregular and the obvious interpretation may not be statistically significant, though strongly suggestive An increased fecal output of calcium, more than an increased dermal output, determined the generally less favorable balance of calcium in the tropical environment

In the same series of studies iron balances were obtained on three subjects during two weeks under comfortable conditions and two weeks under hot humid conditions With iron intakes

somewhat higher in the latter environment because of a greater consumption of tap water, the dermal loss of iron averaged 2 mg per eight hours under comfortable conditions and 10 mg per eight hours under hot-humid conditions The iron balances in five of six possible comparisons, favored the temperate environment, the average difference amounting to over 6 mg per day The results are highly suggestive of an increased iron requirement in a tropical climate due to sweat losses of iron, but the data are inadequate to establish the point with a satisfactory degree of certainty, the probability of a chance outcome being 0 040 In these experiments the intake of iron was abnormally high, 50–60 mg daily The relatively great prevalence of iron deficiency anemias in the tropics in infancy and childhood (Stransky and Davis-Lawas, 1948) may involve excessive losses of iron in the sweat

THE EFFECT OF DIET ON TOLERANCE TO HEAT AND HUMIDITY EXPERIMENTS AND OBSERVATIONS ON HUMAN SUBJECTS

The evidence bearing on the possibility of increasing man's tolerance to a tropical environment by dietary modifications is conflicting Foulger (1942) has reported tests on men working in extreme heat and high humidity indicating a marked increase in the resistance to heat cramps and heat prostration following the ingestion of vitamin C tablets These tests have not been reported, in so far as the reviewers are aware, in sufficient detail to permit critical appraisal

The experiments of Fox (1940) on native workers in the Witwatersrand gold mines of South Africa, referred to above, revealed no benefits to men working in intense heat brought about by ascorbic acid supplementation of a diet of borderline content

Because of claims, widely quoted in the popular press, of special benefits of ascorbic acid for men working at high temperatures, workers at the Laboratory of Physiological Hygiene at the University of Minnesota (Henschel *et al*, 1944) undertook an extensive experiment to test such claims under controlled experimental conditions Forty four normal young men were subjected

to temperatures up to 122°F, and low humidity, for periods of three hours to four days Work on a treadmill equivalent in calorie expenditure to seven times the basal metabolism was imposed daily in six 10 minute work periods alternating with rest periods of 10 minutes The basal diet was restricted in vitamin C content to 20 to 40 mg daily in one series of experiments and to foods, in the other series, of low content of the vitamin A supplement of 500 mg of ascorbic acid was given daily to half of the subjects, the other half receiving placebos

Many observations were made on the test and control subjects during the exposure periods Pulse rates in rest and in work, rectal temperatures, vasomotor stability tests (Crampton's blood ptosis test), rates of sweating, general observations and subjective reports "all failed to demonstrate any significant advantage for the men receiving supplements of ascorbic acid Psychomotor tests and strength tests likewise generally failed to show any advantage in the ascorbic acid supplementation There apparently was a slight gain in flicker fusion frequency related to the extra intake of vitamin C" This test is commonly used as an index of fatigue of the retino cortical system Daily sweat losses ranged from 5 to 8 liters and contained only inappreciable quantities of vitamin C "Heat exhaustion occurred with equal frequency in the vitamin C restricted and the supplemented groups"

The same group of workers (Henschel, Taylor, Mickelsen, Brozek and Keys, 1944) have reported in abstract the results of experiments similar to the above but designed to test the effect on heat tolerance of combined dosages of thiamine, riboflavin and nicotinamide High intakes of these vitamins had no appreciable beneficial effect on the physiological, biochemical or psychomotor functions measured "The rate and degree of acclimatization, the incidence of heat exhaustion and the ability to do hard work in the heat were not influenced by the vitamin supplementation contrary to the claims of others" Some details of these experiments are contained in a report to the National Research Council by Henschel, Taylor and others (1943)

In the course of their experiments on work in the heat as affected by intake of water, salt and glucose, Pitts, Johnson and Consolazio (1944) state, with no amplification "We have been

unable to detect any advantage from administering 200 mgm of ascorbic acid, 20 mgm of thiamine hydrochloride, 20 mgm of riboflavin or large doses of brewer's yeast, either singly or together either during work or the day before"

Experiments possessing a different significance were reported by Droese in 1942 from the Kaiser Wilhelm Institute in Berlin Fourteen subjects were instructed to pedal on a bicycle ergometer to complete exhaustion indicated objectively by high pulse frequency and by hypoglycemia, under two environmental conditions and with or without certain supplements added to their ordinary freely chosen diet, presumably, since no description of the basal diet is given The rooms were maintained at 20°C and 57% relative humidity, and at 39°C and 30% relative humidity The dietary supplements consisted of 50 gm of glucose or 50 gm of glucose + 500 mcg of vitamin B_1 (Betaxin) The supplements were given in cocoa, while during control periods the subjects received cocoa with saccharine added to simulate the sugar supplement

Unfortunately only average results are given with no statistical analysis of the data When the supplements were given in the work period when the subjects felt tired the outcome seemed clear cut The endurance of the subjects was increased in the cool room by glucose alone or by glucose plus the vitamin the increases averaging 14 and 24%, respectively In the warm room, however, the glucose alone was without effect, while the glucose plus Betaxin increased endurance an average of 23% The work capacity in the warm room was less than half that in the cool room but the muscular efficiency, expressed in calories produced per kgm m of work, as well as the rate of sweating, was the same in both rooms When the supplements were administered one half hour before the work periods, some experiments were inconclusive

The author concludes that the vitamin B_1 requirement is increased by work in the heat not because of increased sweating nor of a diminished efficiency of muscular work, but probably because of some circulatory impairment preventing the rapid removal from the muscle of intermediary products of sugar metabolism that accumulate there in the absence of adequate con-

centrations of vitamin B_1 As indicative of circulatory impairment in the heat there was a slight lowering of pulse frequency after glucose plus B_1 as compared with glucose alone However, this lowering of pulse frequency occurred in both the cool and the hot environments

The experiments of Droese were carefully planned and executed The outcome would be clearer if supported by statistical analysis With no knowledge of the thiamine content of the basal diet, it is impossible to decide whether the added 0 5 mg is satisfying an increased requirement in the hot, no symptoms of thiamine deficiency having been observed, whether it is alleviating a non-nutritional condition, such as the favorable effect of niacin in alleviating hepatic damage in the aged (Rafsky and Newman, 1943), or whether it is increasing tolerance to heat as dietary carbohydrates increase tolerance to cold (Keeton *et al*, 1946)

Pitts, Consolazio and Johnson (1944) have failed to detect any effect of the amount of dietary protein on physical fitness in hot climates Van Veen (1942) has called attention to the very small content of fat in the diets of some tropical populations, but without any implication that low fat intakes favor tolerance to heat No investigation seems to have been made of the possible effect on heat tolerance of modifying the proportions of fat and carbohydrates in the diet, similar to the work of Keeton *et al* (1946) and of Mitchell *et al* (1946) with reference to cold tolerance

CONCLUSIONS

From animal experimentation, it may be concluded that in a hot environment the requirement for thiamine is definitely and rather markedly increased while the requirement for riboflavin is markedly decreased There are indications that ascorbic acid requirements may also be increased if the body temperature is raised, and that the sensitivity of animals to rickets may be enhanced in a hot environment However, the methods of maintaining heat balance in most of the lower animals and in man are so different that animal experimentation may be an insecure guide to human needs and reactions in this area of science

Direct experimentation on human subjects, supplemented by observations in the field, show

1 That energy requirements are decreased in a hot climate, as compared to a temperate climate due to a diminished basal expenditure of energy, or to greater efficiency in certain types of muscular work, associated with lighter clothing or to a lessened capacity for work and less motivation or to all three The effect of tropical heat on the basal metabolism is not a consistent one and evidence on this item in the above statement is conflicting

2 The water requirements are definitely increased when sweating is induced and somewhat in proportion to the amount of sweat secreted The daily requirement of water may increase from 2 5 to 3 0 liters per day in a temperate climate to 13 liters or more during work in a hot environment For the maintenance of physical fitness under the latter conditions it is imperative that water losses in the sweat be covered by water ingestion at short intervals During intense sweating, thirst is not an adequate guide to water requirements, though if thirst is satisfied continuously any considerable dehydration may be avoided for the usual working periods

3 The salt (NaCl) requirements of man may be greatly increased from a level of 2 to 5 gms daily under non-stress conditions to 15 to 17 gms daily under conditions of profuse sweating 8 to 10 liters daily This large increase is confined to the period of acclimatization and the salt losses in the sweat need not be replaced continuously, as in the case of water losses In fact, replacement at meal times by the consumption of food seasoned with salt in the usual fashion may be adequate When acclimatization to heat supervenes, salt conservation in sweat and urine greatly lowers the dietary salt needs, which may be but little raised above requirements in a temperate climate In any case, the need for salt tablets, or salinized water during muscular work under tropical conditions, so greatly emphasized five or 10 years ago, seems now to be restricted to unusual situations prior to the attainment of acclimatization

4 There is no adequate statistical evidence that men voluntarily select low protein diets in a hot climate, regardless of food availability and economic status Observations in the field indicate

no benefits in body heat economy from the consumption of low protein diets Laboratory experiments show that protein requirements may be increased slightly by (a) a stimulation of tissue catabolism if pyrexia occurs, and (b) by sweat losses of nitrogen uncompensated by diminished losses in the urine Considering all evidence it may be concluded that protein requirements may be slightly increased in the tropics by some 5 to 10 gms daily

5 The great preponderance of evidence from human experimentation shows that, despite small losses of vitamins in the sweat, vitamin requirements are not appreciably increased over the values in a temperate climate by residence or by work in a tropical climate

6 Due to losses of minerals in the sweat, and, in the case of calcium to fairly consistent increases in fecal losses in a hot environment, man's requirement for iron, and less certainly for calcium, may be increased in a tropical environment The problem deserves further study

7 Attempts to increase man's tolerance to heat, or to accelerate acclimatization to heat, by dietary modifications have not been as extensive as the importance of the problem warrants No evidence has been secured to suggest with any assurance that modification of the proportions of protein, carbohydrate and fat in the diet will improve heat tolerance, but little work has been undertaken with well-controlled procedures in this direction Most of the evidence on vitamins—most of it secured with ascorbic acid—has not revealed any benefits from supplementary doses to diets presumably adequate in vitamins under temperate conditions The case with reference to thiamine and exhausting work in the heat, especially when extra calories are furnished by sugar, needs further study, in view of the evidence of Droese of a favorable effect of the vitamin on the capacity for doing work in the heat

Conclusions concerning the relationship between nutrition and "tropical deterioration,' based largely upon extensive observations of allied troops during the late war, have been expressed by Kark and co workers (1947) The following quotation is noteworthy "In providing rations for soldiers at least three considerations are of prime importance First, a considerable variety of food items should be issued Second, the food items should be

much the same as soldiers are accustomed to in ordinary life, but emphasis should be placed on acceptable foods of high biological value Third, caloric deficits must be avoided From the standpoint of military efficiency, caloric deficiency was an important problem during the war, vitamin deficiencies relatively unimportant"

The proper packaging and storing of foods is emphasized also in these and other reports of a similar nature, since the preservation of perishable nutritional factors—mainly the vitamins—in the diet under the unfavorable conditions of the tropics is as important as the proper selection of foods

Reference may also be made to the article by Johnson (1943) on nutritional standards for men in tropical climates In discussing this subject, the main thesis of this section of the report, one must guard against sweeping conclusions based upon negative evidence As Van Veen (1942) has pointed out, there is much less certain knowledge on human nutritional requirements in the tropics than on requirements elsewhere

Chapter IV

DIET AT ALTITUDE

THE PHYSIOLOGICAL EFFECTS OF ALTITUDE

The physiological effects of altitude are occasioned by diminished atmospheric pressure, diminished partial pressure of oxygen, increased intensity of solar radiation and changes in the proportion of radiations of different wave lengths in the sun's rays These effects are experienced at high elevations on the earth's surface, but particularly in high altitude flying

1 CHANGES IN SOLAR RADIATION Speaking of the solar spectrum as affected by altitude, Laurens (1938) states "On entering the earth's atmosphere 5% of the total radiation (1 93 g cal per sq cm per min) is ultra violet, 52% visible, and 43% infra red Owing to extinction and absorption by the time the radiation reaches the earth's surface the relative amounts have changed and at average heights of the sun with a total radiation intensity of 1 0 g cal per sq cm the distribution is ultra violet 1%, visible 40%, and infra red 59% Total intensity is primarily dependent upon height above sea level, as well as upon seasonal and daily variations, which particularly influence the ultra violet Abbot shows that only 75% of the total solar radiation (the solar constant) reaches a level of 1800 meters, and only 50% to sea level Spring sunlight is the strongest and richest in infra red, the

autumn sun by comparison being richer in ultra violet, the maximum content of which is reached in the summer' (see also Blum, 1945b)

The ultra violet rays are responsible for the nutritional value of sunlight with reference to the functions of vitamin D in the body They are also responsible, on intense application, for tissue injury, such as sunburn, and injury to the cornea, retina, and possibly the lens of the eye But the visible and infra red rays, being more penetrating, exert deep tissue effects The therapeutic effects of long-waved luminous and short-waved infra red rays are well known (Laurens 1936) The effects of visible radiations of different wave lengths on the albino rat have been studied by Allardyce *et al* (1942) and of visible and infra red radiation by Luce Clausen and Brown (1939a, b) Pigment, either natural or artificial, does not appear to protect the deeper regions of the skin from excessive heating due to infra red irradiation (Foster, 1935) Smith and Ruffin (1937) believe that the heating effects of the sun's rays (infra red), rather than the visible rays themselves, are responsible for the exacerbation of dermatitis in pellagrins exposed to sunlight Graybiel Patterson and Packard (1948) have shown that sunburn impairs circulatory adjustment to accelerative force and causes a temporary lowering of blackout threshold in aviators

Kestner (1921) has presented some observations secured upon dogs indicating that sunlight not reduced partial pressure of oxygen, is the effective agent in increasing the hemoglobin content of the blood at altitude These experiments on the effect of sunlight upon blood regeneration, receive support from the observations of Foster (1931) on the effect of irradiation with a quartz mercury arc of rats receiving a milk diet While irradiation did not alter the initial decline in blood hemoglobin, after the fourth week on the anemia-producing diet when the hemoglobin had reached its lowest level, the irradiated, in contrast to the controls, showed a marked recovery However, the outstanding effect of ultra violet irradiation on blood regeneration relates to the red cell count, rather than to hemoglobin concentration, in nutritional anemia (Andes and Beard, 1934) in rats and in hemorrhagic anemia (Laurens and Mayerson, 1931) in dogs In experimental

hemolytic anemia (Mayerson and Laurens, 1931) in dogs, the beneficial effect of radiant energy is exerted upon both red cell number and hemoglobin concentration In previous work (1928), Mayerson and Laurens showed that repeated irradiation of normal animals with the flaming carbon arc stimulates the hematopoietic system to a sustained production of a greater than usual number of red cells The latter finding was not confirmed by Sinclair (1933) on pigs, nor does the pig, made anemic by milk feeding, respond in increased red cell count and hemoglobin formation to the daily application of radiant energy from a mercury vapor lamp over a period of 38 days

2 EFFECTS OF DIMINISHED ATMOSPHERIC PRESSURE The literature concerned with the physiology of high altitude has not been reviewed as adequately as the importance of the subject would warrant The earlier literature is reviewed by Schneider (1921) and later contributions are discussed in a small book by Gemmill (1943) Gemmill has also published a later review (1946) covering reports printed during 1944 and 1945, but unfortunately the restricted and confidential material secured by the Army, Navy, and civilian laboratories during the war years was not made available to him, although "Most of the unpublished material cannot possibly give aid or comfort to any of our enemies, past, present, or future" The article by Ivy (1946) on high altitude problems in aviation may be consulted to advantage, also Books on aviation medicine contain physiological information too, and among such books the following may be cited Armstrong (1943), Jokl (1942) and Ruff and Strughold (1942) An Italian monograph by Tommaso (1946) on fundamentals of physiology and pathology of man in flight has been reviewed favorably

a Respiratory heat and water loss This review will consider only a few selected topics in the general field of the physiology of altitude The effect of altitude on the respiratory metabolism is of direct interest to the subject of this report Matthews (1932–33) has concerned himself with the heat loss from the body through the lungs and respiratory passages, in vaporizing water, releasing CO_2 from solution and warming the inspired air At ground level in dry cold air, 15 to 25% of the total heat production is lost in this way, while at high altitudes a much greater

proportion is so lost, due to the rapid respiration required to obtain the needed oxygen The computations show that "unless the inspired and expired air differ in oxygen tension by about 5 mm, even if clothing is so perfect that it prevents any heat loss from the skin, the body temperature cannot be maintained By extrapolation from figures for alveolar air up to 23,000 ft it appears that these conditions will be realized somewhere round about 30,000 ft" Marshall (1946) considers the respiratory water loss at ground level and at altitude and finds it to be only slightly higher per liter of exhaled air at 30,000 ft than at sea level A later report by Marshall and Specht (1949), using correlation analysis of his data, suggests that respiratory rate changes are more important in determining aqueous vapor pressures of respired air than are tidal and minute volumes

b Basal metabolism Although the basal metabolism of man or of animals is commonly, and rightly, considered as among those physiological measurements most accurately made and most constant from day to day, the demonstration of the effects of changing environmental conditions on metabolism when these effects are small is a difficult technical problem This is true because the possible effect is a measurement of a difference between two much larger quantities, one the measurements *sans* the effect and the other the measurement with the effect Hence the experimental evidence for such effects is so often confusing and equivocal This situation is illustrated by the discussions above on the effect of heat and of cold on metabolic rate With reference to altitude, the problem is further complicated by technical difficulties inherent in low-pressure physiology such as the 'blowing off' of carbon dioxide due to an altered type of respiration, and the respiratory removal of gaseous nitrogen from the tissues The first phenomenon disturbs the metabolic significance of the respiratory quotient of the subject and of the output of carbon dioxide, the latter phenomenon would contraindicate the use of a closed circuit spirometer type of instrument, such as the Benedict-Roth, because of the accumulation in it of expired excess nitrogen These phenomena, of course, are temporary, terminating after a period of adjustment of variable length

Lewis, Iliff and Duval (1943) have discussed critically the evi-

dence reported in this country on basal metabolism at different altitudes on the earth's surface, and have concluded, in harmony with their own observations, that altitudes varying from sea level to 7,148 ft are without appreciable effect on the basal metabolic rate of men and women Where an effect has been presumed the indications point to an increased metabolism at altitude Herxheimer, Kost and Ryjaczek (1933) refer to European work up to that date and report observations of their own on four subjects upon whom many basal metabolism measurements were made at Berlin and at Jungfraujoch at an altitude of 11,384 ft The Douglas-bag method was used in these studies No consistent differences in oxygen consumption under basal conditions were noted at the two localities Quevedo (1947) also has observed no appreciable effects of altitudes up to 4,517 m on the basal metabolism of 46 persons living in Peru

For higher altitudes, simulated in decompression chambers, the evidence is not readily reconciled Clinton, Thorn and Davenport (1946) observed a decrease in basal metabolism (at ground level) of subjects exposed to 12,000 ft for three hours daily over a four-week period However, the decrease was slight (4 or 5%) and was probably in the authors' judgment a result of an inadequate caloric intake evidenced by a slow decline in body weight Also, in unpublished experiments by Eckman *et al* from the Aviation Research Laboratory of Columbia University (1945), and by Nims and Olmstead (1945), no change in the basal oxygen consumption at altitude was noted In earlier work, Christensen (1937) noted a linear relationship between work intensity in human subjects and oxygen uptake, undisturbed by altitudes up to 5,340 m , from which it may be concluded that, at the no work level, oxygen uptake is also undisturbed within this altitude range However, Cook (1945) found that a decrease in total pressure, with no reduction in the partial pressure of oxygen, inhibited the growth of chick embryos, interfered seriously with the metamorphosis of the meal worm, lowered the heat production of anesthetized and unanesthetized mice, and depressed the resting (not basal) metabolism of eight human subjects in proportion to the diminution in total pressure The depression in human metabolism amounted to 24% at 38,000 ft In the latter experiments,

the time after the meal is not indicated and the temperature is not always given The author concludes that

"The evidence derived from isolated cells and from several groups of mammals appears to support the thesis that reduction of total gas pressure, quite independent of oxygen tension, alters the normal oxidation metabolism Concerning the biophysics of the process, little if anything can be said at present."

Since the results of Cook were criticized because the subjects were not under basal conditions and because of possible technical errors, Berg and Cook (1946) carried out later experiments on the carbon dioxide production of men, both under basal and non-basal conditions, at sea level and at a pressure equivalent to an altitude of 30,000 ft It is to be noted that the tests at altitude were started a few minutes after the desired altitude was attained, and in all tests the subjects breathed pure oxygen With nine subjects there was an average depression in the basal carbon dioxide production at altitude of 6 4%, exhibited by all but two of the subjects The average depression was significant at the 1% level Under non basal conditions the depression in CO_2 production averaged somewhat higher and was highly significant In these experiments no attempt was made to determine whether the depression in metabolism is caused by reduced total pressure or reduced partial pressure of oxygen The results would be of more significance for the purposes of this report if some assurance could be felt that the tests were not carried out during a period of adjustment to the lowered pressure

c Aeroembolism Aeroembolism or decompression sickness, is a result of diminished total atmospheric pressure and is now known to be caused by the liberation of gases, mainly nitrogen, from solution in the tissues of the body In a strict sense, aeroembolism should refer to the formation of gas bubbles within the circulatory system, but the term has been extended to cover bubble formation in any of the tissues The symptoms of aeroembolism will depend upon the location of bubble formation, whether in the joints (the "bends"), the pulmonary circulation (the "chokes"), the brain ("staggers"), or elsewhere Smedal and Graybiel (1948) have expressed the belief that an increase in ease of fatigability following mild decompression (20,000 ft) may be

more important than symptoms occurring during decompression

There have been many recent contributions to the problem of aeroembolism, but only a few will be referred to here The pathogenic factors and pathological consequences of decompression sickness are considered at length by Catchpole and Gersh (1947), the symptomatology by Gray and associates (1946), the relationship of aeroembolism to traumatic calcification by Allan (1945), and the incidence of decompression sickness, and its various manifestations (including syncope) by Brown (1946), Motley *et al* (1945) and Smedal, Brown and Hoffman (1946), with reference to high altitude flight Houston (1947a) has studied the occurrence of 'bends," scotomata and hemianopsia at altitudes below 20,000 ft According to the latter author "Pilots who make repeated rapid ascents, even to moderate altitudes, may be expected to experience bends, and perhaps visual defects, even as low as 18,000 feet' Behnke (1941–42, 1945 1947) has directed particular attention to the relationship between the incidence of 'bends" and the fat and water content of the body Obese persons are more susceptible to decompression sickness following ascent to high altitudes or from diving depths than men of normal weight, because of the greater solubility of nitrogen in fat than in water The tolerance of various species of animals to rapid decompression parallels values for basal metabolism per kgm of body weight, according to Behnke

The recurrence of decompression sickness on re ascent to high altitude (38,000 ft) after variable periods of rest at ground level was reported by Rodbard (1947b), and the effects of cold and rate of ascent on the disease incidence by Griffin and others (1946) Hodes and Larrabee (1946) observed a close relationship between alveolar carbon dioxide tension and susceptibility to decompression sickness, though the cause of the relationship is not known, it may involve acid-base changes Quoting from this paper " susceptibility increases with pCO_2 Subjects were forced to descend whenever the alveolar pCO_2 was more than 43 mm Hg (seven cases) In contrast no subject was forced to descend when his alveolar pCO_2 was less than 38 mm Hg (five cases) Between 38 and 43 mm Hg subjects were forced to descend in 57% of their tests (61 cases) "

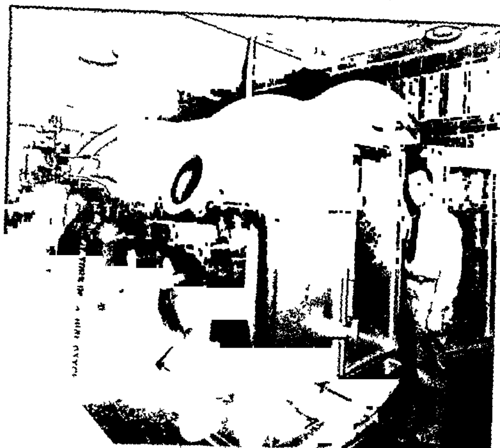


Figure 6 The decompression chamber at the University of Illinois in Urbana The picture shows the entrance to the chamber, the oxygen supply tanks and manifold entrance lock, observation port and control instruments including air valves altimeter and rate of climb indicator (Courtesy of Professor M K Fahnestock)

decompression under conditions designed to minimize coincident anoxia, noted thoracic and abdominal distention in all animals, with hemorrhages in the pulmonary and gastrointestinal systems in some With explosive decompression of sufficient severity, bradycardia and a drop in systemic blood pressure occurs In a later paper (Whitehorn Lein, Edelmann, and Hitchcock, 1947), a rise in cerebrospinal fluid pressure was observed to result from explosive decompression of anesthetized dogs, the rise is considered to be a reflection of a similar rise in intrathoracic pressure' Corey (1949) studied the factors in explosive decompression injury in rats Aeroembolism and anoxic anoxia were the major factors in the etiology of the condition, while intrapulmonary gas expansion was a relatively minor factor in the cause

of death In experiments on human subjects, Hitchcock, Whitehorn, and Edelmann (1948) concluded that "explosive decompression exerts no significant effect on the ability of subjects to tolerate an altitude of 45,000 feet with pressure breathing," and that "explosive decompression, within the rates and ranges used in these experiments, does not constitute a serious hazard to normal human beings"

d Abdominal gas During decompression, gases present in the gastrointestinal tract, whether swallowed or formed there, will expand and under certain conditions may cause abdominal pain, at times incapacitating in its severity Blair *et al* have recently made an intensive study of this phenomenon at the Department of Physiology, University of Rochester, School of Medicine and Dentistry, under a contract with the Office of Scientific Research and Development (1943) The gas content of the digestive tract for adult male subjects is about 1 liter (Blair, Dern, and Bates, 1947), but is subject to great variation on account of variation in the amount of air swallowed and the amount of gas produced in the tract by fermentation In studies of intestinal gas in simulated flight to 35,000 to 38 000 ft Blair, Dern, and Smith (1947) used nine subjects and over 109 flights Among the conclusions drawn from these investigations, the following may be mentioned (a) Difficulty with abdominal gas in flight is dependent not so much on the quantity as on its distribution in the tract, incapacitating pain being associated with excessive amounts in the lower part of the small bowel, (b) the only fairly consistent relation of gas discomfort to particular items of a freely chosen diet is found with carbonated water drunk prior to flight and with the consumption of melons, (c) while the ordinary variations of the proportions of protein, carbohydrate and fat in the diet seemed to be unassociated with susceptibility to abdominal gas pains in flight, extreme variations presented a different picture in that "high-protein" diets (19% of total calories as protein) with high fat content (53% of total calories) proved definitely superior to high-carbohydrate and normal diets in lowering the incidence of abdominal pain and its severity

The gaseous exchange between the blood and the lumen of the gastrointestinal tract was studied by McIver, Redfield, and Bene-

dict (1926), who developed exponential equations for predicting the absorption of oxygen and carbon dioxide under different pressure gradients. This phenomenon was recently reinvestigated by Pogrund (1947), and Pogrund and Steggerda (1948), using human subjects. Of special interest to this discussion is the

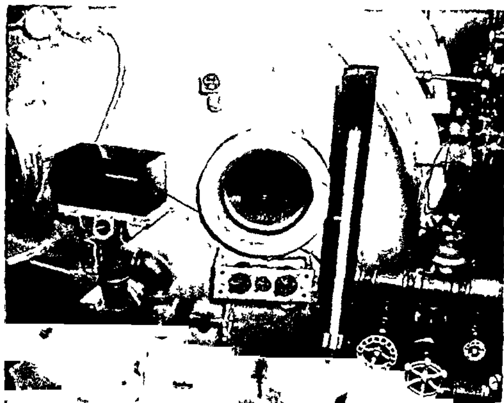


Figure 7. The decompression chamber at the University of Illinois, Urbana The picture shows the rear end of the chamber with chamber controls, including air valves, altimeter, rate of climb indicator, oxygen supply manifold, intercommunication speaker, and observation port. (Courtesy of Professor M. K Fahnestock)

demonstration by Pogrund that oxygen inhalation, by lowering the partial pressure of nitrogen in the blood, will appreciably increase the absorption of nitrogen from the intestinal tract. Hence, denitrogenation prior to flight will tend to decrease intestinal gases and the incidence of gas pains, as well as the incidence of aeroembolism

3 Some effects of diminished partial pressure of oxygen: anoxic anoxia. The profound metabolic effects of altitude are

due to the low partial pressure of oxygen in the inspired air, leading to profound changes in the respiratory process, in the oxygen transport to the tissues and in the capacity of the tissues to perform their normal functions under hypoxic conditions. Only brief

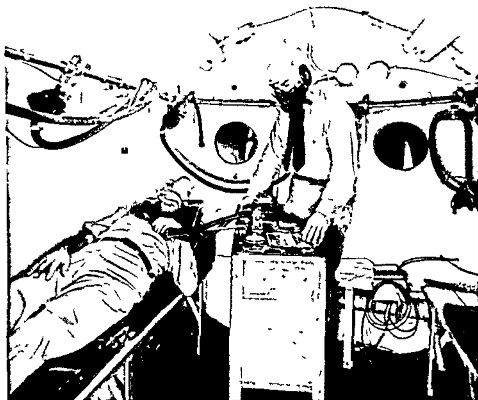


Figure 8 The interior of the decompression chamber at the University of Illinois, Urbana, with reclining subject and metabolism equipment and standing observer with oxygen supply mask (Courtesy of Professor M K Fahnestock)

reference can be made here to the large volume of literature dealing with these effects of anoxic anoxia

a. Effects on respiration. Dripps and Comroe (1947) have reported studies of pulmonary and cardiovascular response to the inhalation of air containing low percentages of oxygen in human subjects at rest The circulatory system (pulse rate) is readily stimulated by a reduction in oxygen percentage from 21 to 18 Respiration is stimulated only slightly at 16% oxygen and markedly only at 8%. "It is likely that the vasomotor center is

stimulated more and/or depressed less by anoxia than is the respiratory center" Chambers *et al* (1947) from experiments on unanesthetized dogs trained to breathe through a mask and valves, conclude "that, during anoxemia, a chemical factor, other than carbon dioxide, as well as reflex stimulation from the aortic and carotid receptors is responsible for the respiratory response The ineffectiveness of carbon dioxide as a respiratory stimulant in anoxia has been demonstrated a number of times, most recently by Ivy, Grodins, Adler, and Snapp (1947) In fact, in 11 tests on five dogs, carbon dioxide inhalation during anoxia produce respiratory depression rather than stimulation, under condition that could not have involved anoxic collapse According to D'Angelo (1946c) the modifications in the respiratory metabolism at altitude are "collectively indicative of a respiratory alkalosis"

Recent studies of alveolar air during simulated flights to high altitudes by Fenn, Rahn, and Otis (1946) and by Rahn and Otis (1947), and of the oxygen pressure gradient from alveolar air to arterial blood during rest and exercise at sea level and at altitude by Lilienthal, Riley, Proemmel, and Franke (1946), should be consulted for information on these topics Weterings (1948) emphasizes the importance of the chemoreceptors in mediating alterations in pulmonary ventilation in response to alterations in alveolar pressure of either oxygen or carbon dioxide

One of the outstanding contributions of physiological research to military aviation is the development of an oxygen inhalation equipment for pressure breathing, first described by Gagge, Allen and Marbarger (1945) By increasing the oxygen pressure in the lungs throughout the respiratory cycle by eight to twelve inches of water, it is possible to maintain the effectiveness of oxygen inhalation up to an altitude of 45,000 ft, or with some individuals to 50 000 ft Studies on the use of this equipment have been reported by Barach and associates (1946, 1947) and Eckman, Barach *et al* (1947) Reports by Bateman and Sheard (1946) on the insignificant effect of pressure breathing on the cutaneous temperature of the extremities, and of Molomut and Allen (1946) on effects of cardiac output and the circulation, are worthy of consultation Although pressure breathing may increase greatly

the work of respiration (Rahn, Otis, Chadwick, and Fenn, 1946), its effect on the total metabolic rate is probably slight (Bateman and Sheard, 1946) In the experience of Ivy, Atkinson, Adler, Burkhardt, and Thometz (1944), pressure breathing in most cases has no effect on the total incidence of bends and chokes, although an occasional individual highly susceptible to these conditions may show marked improvement during pressure breathing Werko (1947) has published a Swedish monograph on the influence of positive pressure breathing on the circulation in man, while Drury, Henry, and Goodman (1947) have noted a depression in renal function following continuous pressure breathing

b Some effects on the circulatory system In normal young men, exposures of 10 to 48 minutes to pO_2 corresponding *to altitudes of 18 000 to 28 000 ft does not induce cardiac dilatation* nor affect appreciably the stroke volume or efficiency (Keys, Stapp, and Violants, 1943) As the respiratory rate increases, the blood pH shifts to the alkaline side due to the washing out of CO_2 (Clarke, Marshall, and Nims, 1944) In dogs, the blood-clotting time is shortened in hypoxia, sometimes to one half the normal value (Griffie, Chardon, and Ruffieux, 1942–44), an effect that does not occur in adrenalectomized dogs Quastel and Racker (1941) showed "that a substance, important in the kinetics of blood coagulation is produced with greater ease from tissues when these are incubated under anaerobic conditions than when incubation occurs aerobically,' observations that may have a bearing on the hypoxia of high altitude flight Capillary permeability does not seem to be appreciably modified by anoxemia (Hopps and Lewis, 1947) According to Chardon and Fourrier (1947), the reflex mechanism of cardiac acceleration in anoxia, rather than direct central action is by far the more important in inducing tachycardia

The most important effect on the blood of diminished oxygen pressure at high altitudes relates to the oxygen saturation of the hemoglobin and the oxygen transport to the tissues Arterial oxygen saturation, according to Houston (1946a), is extremely sensitive to even small changes in pulmonary ventilation "Increasing the resting ventilation by half, a change of which the subject is scarcely aware, may increase arterial saturation by 10

to 20%." But the predominant effect of increasing altitude is a bin oxygen saturation at sea level to about 89% at 10,000 ft and to 70% at 20,000 ft while breathing air. While breathing pure oxygen, these percentages are greatly increased, only dropping to 70% at some 45,000 ft. These percentages may fall appreciably at any altitude during a short period of moderate to heavy work (Lilienthal, Riley, and Proemmel, 1946). Starr and McMichael (1948) emphasize the considerable variation in the arterial oxygen saturation of different healthy persons breathing the same rarefied air, a variation that could not be explained by differences in their total volume of respiration or circulation.

c. Effects on energy metabolism. In a preceding section it was pointed out that, according to available evidence, the basal metabolism of man is not appreciably affected by moderate altitudes attainable on the earth's surface. The evidence for higher altitudes is less complete, but indicates either no effect or depressions of 6 to 8%, attributed not to anoxia but to low total atmospheric pressure.

The metabolism of energy is normally stimulated by the ingestion of food, the specific dynamic action, but particularly by muscular work. These stimulations call for an increased consumption of oxygen. Under anoxic conditions the supply of oxygen to the tissues is limited. An important problem, therefore, is the effect of this limitation in oxygen supply on specific dynamic action and on the metabolism of muscular work. Giaja (1938) classifies the heat-producing oxidations in homeotherms into two categories, i.e., those that are not affected by a decrease in oxygen tension, and those that are. In the former category he places the basal metabolism and the calorigenic actions of certain drugs. In the second category he places the specific dynamic action of protein. However, in a recent Russian report (Alekseev *et al.*, 1945), which we have seen only in abstract, the specific dynamic action of a high-protein meal (broiled lean beef) was tested at an altitude of 4,200 m. The increase in basal metabolism of four subjects was not substantial and the specific dynamic action was said to be normal. The subjects were kept warm throughout these

tests and the authors surmise that previous reports of a decrease in specific dynamic action were evidently due to cold exposure

Fuhrman, Fuhrman, and Field (1945) measured the rate of oxygen uptake *in vitro* of the tissues of rats subjected to progressively decreasing pressures until death occurred When compared with control tissues, the oxygen consumption of the liver and cardiac muscle of the anoxic rats was found to have decreased 20% and 35%, respectively, while that of the kidney cortex, the skeletal muscle and the cerebral cortex was essentially unchanged

While an oxygen supply in excess of normal has been shown to have no favorable effect on the working metabolism of a man or on the recovery period (Benedict, Lee, and Strieck, 1934), a deficient supply of oxygen, as at altitude, has been shown repeatedly to limit the capacity for muscular work (see, for instance, Foltz and Ivy, 1943, Christensen, 1945, and Cook and Strajman, 1945) and to prolong the recovery period The mechanical efficiency of work is not, however, impaired according to the very careful experiments of Christensen, who showed further that up to an altitude of 5 340 m (17,520 ft) the unreduced ventilation volume increases up to 120 liters per min during muscular work, while the reduced ventilation volume per unit of oxygen uptake remains constant Christensen believes that the pulmonary ventilation is the factor limiting work capacity at altitude, while Cook and Strajman conclude that the basic disturbance is an increase in the rate at which an oxygen debt is incurred and a retardation in the rate of recovery At altitudes as high as 40 000 ft, however, there may be some impairment in muscular efficiency (Hall and Wilson 1944) Van Middlesworth (1949), using radioactive iodine (I^{131}), has made the interesting observation that in rats exposed to a simulated altitude of 27,000 ft, the protein bound iodine in the blood plasma undergoes a sharp reduction This phenomenon "may result from an almost complete suppression of a portion of the thyroid activity" According to Blood *et al* (1949), thyroxine administration is detrimental to the survival of rats at low oxygen pressures, although thiouracil in doses sufficient to increase thyroid size three fold was not protective

Edwards (1936) observed an increase in blood lactic acid after

standard work performance on first going to high altitudes, but that after acclimatization lactic acid values similar to those at sea level are found for a given performance The following quotation suggests a reasonable interpretation of the effect of anoxia on muscular metabolism

"The ability to perform work is lessened progressively with increase in altitude, hence also the ability to accumulate lactic acid Only slight increases over rest values of lactic acid are found during work at 6 14 km The inability to accumulate large amounts of lactic acid at high altitudes suggests a protective mechanism preventing an already low arterial saturation from becoming markedly lower by shift of the O_2 dissociation curve through acid effect It may be that the protective mechanism lies in an inadequate oxygen supply to essential muscles, e g, the diaphragm or the heart"

Rothschuh (1947) has studied the decrease in the metabolic rate of guinea pigs exposed to decreasing atmospheric pressures A lowering of body temperature and a changing behavior of the *animals began simultaneously with the decrease in oxygen consumption*

According to Schneider and Clarke (1929) "Healthy unacclimatized men can do a moderate amount of physical work at a barometric pressure of 290 mm (equivalent to an altitude of 25,000 ft) for a short time without much distress and without harm" Karpovich and Ronkin (1946) have compared the oxygen consumption of men varying in weight from *120 to 220 pounds* while working on a special ergometer simulating the cockpit of a plane While muscular efficiency does not vary with body size there are, of course, large differences in lung ventilation and oxygen consumption The energy expenditures of trained and student pilots in manipulating an airplane in flight have been measured by Corey (1948) According to Schmidt (1939) oxygen deficiency during muscular work at altitudes of *4 to 5 km* leads to complete collapse in a short time, injury to the nervous system, rather than to the muscular system, being the deciding factor

d Effects on carbohydrate metabolism Anoxia in some degree of intensity may be expected to modify metabolic reactions, but the

surprising thing is that the modifications produced are so slight Since the efficiency of muscular work is not affected at altitude, the essential reactions involved in muscular metabolism are not disturbed, except quantitatively in limiting the capacity for doing work Rosenthal, Shenkin, and Drabkin (1945) have reported experimental findings on dogs suggesting "that a destruction of respiratory enzymes or a critical deficiency of co-enzymes in the brain is not a primary consequence of anoxia nor do such factors account for the development of irreversible functional and histological alterations that may follow anoxia"

In experiments on fasting guinea pigs, Murray and Morgan (1946) compared blood sugar levels and tissue glycogen contents at sea level and at 20,000 ft The changes were not as striking as previously reported by others, consisting of a significant rise in blood sugar but no significant increase in liver glycogen and an actual decrease in total carcass glycogen Wickson and Morgan (1946) observed a significant increase in blood sugar and liver glycogen in fasted rats exposed to reduced pressure, but no change in muscle glycogen Riboflavin deficiency prevented these former effects, probably by impairing gluconeogenesis or glycogenesis or both A later report of this work in abstract (Reade and Morgan, 1949) indicates an increased adrenocortical activity in riboflavin deficiency, followed by adrenocortical exhaustion Either cortin or riboflavin seemed capable of restoring adrenocortical function to normal The previous experiments on laboratory animals revealing an initial hyperglycemia, followed by a moderate hypoglycemia were reported by Van Middlesworth, Kline, and Britton (1944) Exposure of rats for 24 hours to diminished pressure induced substantial increases in liver glycogen according to Evans (1934) and Nims, Langley, and Clarke (1946) According to the latter workers, maximum liver glycogen was observed at a simulated altitude of 20,000 ft, with lesser accumulations at higher and lower altitudes—a truly anomalous observation A depletion of liver glycogen on exposure of animals to low pressures for 5 hours was also reported by Lewis *et al* (1942) Thorn *et al* (1942) and Reynolds (1947) found that discontinuous exposures of animals to lower pressures leads also to appreciable reduction in liver glycogen stores

In dogs, anoxia induced at 24,000 ft for 15 minutes is associated with hyperglycemia (Stickney, Northup, and Van Liere, 1948) The following are offered as possible etiologic factors for this elevation in blood sugar and reduced sugar tolerance (1) insufficient oxygen for the proper functioning of enzymatic systems involved in carbohydrate metabolism, (2) increased activity of the sympathetico adrenal system, and (3) increased adrenal cortical activity (Kelley and McDonald, 1948)

The effect of anoxia on the secretion of adrenaline has been studied recently by Malméjac and Chardon (1947), Bulbring Burn, and De Elio (1948), and Surtshin, Rodbard, and Katz (1949) The results cannot be summarized in the space available for this topic

The hypoglycemic effects of insulin in rabbits are antagonized by brief periods of anoxia, with a quicker recovery of the blood sugar to normal levels, while prolonged anoxia leads to an aggravation of the hypoglycemia and a progressive fall of the blood sugar (Gellhorn and Packer, 1940) Glickman and Gellhorn (1938) observed in rats that insulin convulsions are greater in severity with a shortened latent period under low pressure

Another type of disturbance in carbohydrate metabolism induced by anoxia has been reported by Greig and Govier (1943) in experiments on dogs *In vitro* studies on the tissues of animals subjected to anemic anoxia or to anoxic anoxia revealed an extensive dephosphorylation of cocarboxylase, evidently produced by tissue anaerobiosis

In man, the disturbances of carbohydrate metabolism by altitude are not so clear cut, possibly because the recorded observations were generally carried out at the moderate altitudes obtainable on the earth's surface Ferraloro (1929) observed higher elevations of blood sugar after a large dose of glucose on a high mountain (2,900 m) than at a lower level (240 m) The sugar tolerance was not modified within this range of altitude In acclimatized subjects, the effect of altitude (up to 6,140 m) on blood sugar was less clear (Forbes, 1936) The behavior of the blood sugar in work was approximately the same at all altitudes Baičenko and Krestovnikov (1933a) found no relation in a group of men between elevation (4,200 to 5,633 m) and blood sugar

level, while Kreienberg and Gerke (1942) obtained a decrease in the blood sugar in man during the inhalation of an oxygen-low gas mixture corresponding to an altitude of 8,000 m The results are interpreted to mean a diminished sugar output by the liver in anoxia

Leipert and Kellersmann (1942) gave a group of young men 50 gms of glucose and then subjected them to altitudes of 5,500 to 6,200 m The height of the hyperglycemic phase of the blood sugar curve was little altered by decreased pressure, but the hypoglycemic phase was shortened or completely suppressed Phosphate metabolism was markedly affected by hypoxia, the inorganic phosphorus of the blood and of the urine was notably decreased The decline in inorganic phosphorus in the blood was compensated by a marked increase in the content of phosphoric acid ester According to the authors, phosphorylation, a reaction that under normal conditions is independent of oxygen supply, becomes a regulating mechanism in hypoxia making adaptation to an increased carbohydrate turn over possible

Bryan and Ricketts (1944) obtained no evidence that the human adrenal cortex is influenced by chronic intermittent anoxia, in contrast to the results of animal experiments Pincus and Hoagland (1943) observed an increased excretion of ketosteroids in the urine of men after test flights, correlated with flying ability

An increased lactic acid content of the blood in men at altitude seems clearly established (Baičenko and Krestovnikov, 1933b), especially at altitudes above 18,000 ft (Friedman, Haugen, and Kmieciak, 1945) At the higher altitudes the pyruvic acid level in the blood increased also Both changes were prevented by breathing oxygen The observations of Hartmann and Muralt (1934) are not so clear cut Tepperman and Tepperman (1948) observed that the blood lactate is much higher in human subjects following measured exercise at 15,000 ft than at sea level, and that muscular training hastens the disappearance of lactate from the blood The hypoglycemic episode following glucose given intravenously seemed to be more prominent at altitude than at sea level

It is interesting to note that while alcohol absorption in human subjects increased at high altitudes, its normal slow rate of removal from the blood is similar at ground level and at altitude

(Bornstein and Loewy, 1931) However, after alcohol ingestion the R Q is lower at altitude, approaching that of the combustion of pure alcohol At neither level was a specific dynamic action of alcohol observed Boeri and Vacca (1948), using dosages of 0 48 gm of alcohol per kgm of body weight, observed a more rapid elevation of alcohol levels in the blood at 450 mm of Hg than at ground level, but also a more rapid disappearance

e Effects on nitrogen metabolism Certain abnormalities in the nitrogenous components of urine have been observed at altitude In young fasting pigs exposed to low percentages of oxygen in the inspired air (7 to 9%), Brunquist, Schneller, and Loevenhart (1924) noted generally (in six out of seven pigs) an increased nitrogen elimination, an unaltered proportion of urea and ammonia nitrogen, a lowered creatinine output and a greatly increased output of creatine in all cases There was also an increased excretion of organic acids and of acetone The most striking outcome of these experiments, the increased creatine output, suggests a marked acceleration of the endogenous nitrogen metabolism The observations on rats reported by a group of Japanese investigators (Nakamura, Shimura, and Tachisawa, 1944), seen in abstract only, indicate an increased output of creatinine up to an altitude of 4,000 m (13,120 ft) and then a decrease at higher altitudes

In human urine secreted at altitude, Hopf (1929) noted a greatly decreased proportion of urea nitrogen on total nitrogen (59%), and Loewy (1930) a percentage of 75 Sundstroem's (1919) observations of the protein metabolism of men at different altitudes are inconclusive Residence in high mountains has been associated with an increased porphyrinuria by Lang (1939a, b) and with an increased occurrence of imidazole bodies in the urine by the same investigator in the same year

f Anoxia and ascorbic acid metabolism Sacerdote (1938a, b) has observed in guinea pigs and rabbits subjected to low oxygen pressures a notable increase in the ascorbic acid content of the blood and a decrease (with the guinea pigs) in the ascorbic acid content of the adrenals Tepperman *et al* (1947) noted a slight decrease in the ascorbic acid content of the adrenal glands of adult male rats as the altitude increased up to 25,000 ft Female

rabbits kept in an atmosphere of 15% oxygen for two months on a diet free of ascorbic acid exhibited (Borsuk, 1949) a sharp reduction of the plasma ascorbic level to zero in 50 to 60 days with the development of typical scorbutic symptoms, while the control animals at normal pressures showed little changes in blood plasma ascorbic acid and did not develop scurvy Only the abstract of this apparently important article was available to the authors

g *Effects on the alimentary tract.* Van Liere has been particularly active in studies of the effect of anoxia on the alimentary tract and his review article (1941) may be consulted to advantage His book on anoxia and its effects on the body (1942) includes discussion of the alimentary tract as well as other major systems of the body From the nature of the problem and the experimental procedures that must be used in its solution, most of the investigations of the effect of anoxia on the digestive system have involved the use of laboratory animals

The gastric emptying time of rats fed corn oil and then exposed to a partial pressure of oxygen of 53 mm Hg (7 03% oxygen) for periods up to four hours was initially accelerated, but at the end of four hours there was no significant difference in the amount of fat remaining in the stomach between exposed and control animals (MacLachlan, 1946) In human subjects, Van Liere (1937) has observed a definite prolongation of the emptying time of the stomach during anoxemia, the altitude threshold for persons at rest lying between 6,000 and 8 000 ft Nimeh (1947), also working with human subjects, has confirmed the findings of Van Liere On the other hand McDonough (1943), using a group of 19 men, noted that barium sulfate passes through the stomach and progresses through the small intestine in approximately the same manner when at simulated altitudes of 38,000 ft for two hours as when at ground level Anemic anoxia in dogs has been found to accelerate the propulsive motility of the small intestine while anoxic anemia has an antagonizing effect (Van Liere, Northup, and Stickney, 1944, see also Van Liere, Northup, Stickney, and Emerson, 1943) The decrease in the propulsive action of the small intestine at a simulated altitude of 18,000 ft was confirmed later on rats by Van Liere, Crabtree, Northup, and Stickney

(1948) According to Malméjac and Chardon (1942–44), gradual decompression in dogs caused, first, a short period of hyperactivity of the intestine and then hypotony at the equivalent of 5,000 m These apparently conflicting results on gastrointestinal motility under anoxia are not readily reconciled

Anoxia seems to depress the secretion of saliva (Filippovich 1940) more readily than the basal secretion of the stomach (Van Liere and Vaughan, 1941), which in turn is depressed at higher pressures than the secretion of intestinal juice (Northup and Van Liere, 1939, Pickett and Van Liere, 1939) Gastric secretion provoked by food responds sooner to the depressing effects of anoxia than does the basal secretion These facts may be interpreted to mean a decreasing oxygen requirement gradient In man, also low oxygen pressures depress the secretion of HCl in the stomach (Hartiala and Karvonen, 1946)

In cats and dogs, no degree of anoxemia compatible with life has any appreciable influence on the absorption of water from the stomach (Sleeth and Van Liere, 1937b), but absorption of water from the intestine is accelerated at low oxygen pressures (equivalent to 10 56% of oxygen and less) (Van Liere, David, and Lough, 1936) Anoxia depresses the intestinal absorption of sodium chloride but not that of sodium sulfate or magnesium sulfate at pressures of oxygen compatible with life (Van Liere and Sleeth, 1936, Van Liere and Vaughan, 1940, and Van Liere, Northup, Stickney, and Richard, 1947) Only extreme degrees of anoxia depress the absorption of fat (MacLachlan and Thacker 1945) or of glucose and glycine (Northup and Van Liere, 1941)

b Anoxia and renal function A marked depression in urine volume at low partial pressures of oxygen has been reported for the dog by Van Liere *et al* (1935–36), Malméjac (1944), and Malméjac, Chardon, and Cruck (1945) In the rat, however, Silvette (1943) observed a polyuria on exposure for three hour periods to low barometric pressures, somewhat in proportion to the pressure imposed In anemic anoxia, induced by carbon monoxide poisoning, the urine volume decreased

The effect of anoxia on renal function in dogs has been studied intensively by Kelley and McDonald (1948) and McDonald and Kelley (1948) In severe anoxia, equivalent to an altitude of

24 000 ft, renal vasoconstriction occurs to make more blood available to the body " The whole mechanism of renal circulatory adjustments to anoxia seems to be set to insure an effective glomerular filtration rate " " Under conditions of anoxia the urinary output is usually decreased, but may be occasionally increased However, as one approaches a critical level of atmospheric oxygen tension (about 45 mm Hg in dogs) renal *blood flow and urine formation cease The normal kidney is* remarkably resistant to rather prolonged periods of anoxia This ability of the kidney to maintain its viability under prolonged periods of anoxia is coupled with the marked inhibition of oxidative systems in the kidney "

In carefully controlled experiments on human subjects exposed three times weekly for two hours to a simulated altitude of 18,000 ft, Burrill, Freeman and Ivy (1945) noted a temporary rise in the excretion of sodium potassium and chlorine and in urine volume, followed by compensatory reduced excretions so that the totals for the 24 hour period were unaltered During prolonged exposures to 8 000 and 10 000 ft simulated altitudes, no appreciable change in total urine output of men was observed by D'Angelo (1946a) under conditions of restricted food and water intake, but the renal excretion of phosphorus was significantly decreased

A general brief discussion of anoxia and renal function has been presented by Macgraith and Havard (1946)

1 Effects on the nervous system The nervous system is most sensitive to anoxic anoxia Barach (1937) calls attention to the terrible weariness and restlessness following a day's mental work at 11,500 ft, and the increased fatigability at somewhat higher altitudes and the slowness and clumsiness at all work Brown *et al* (1944) describe in some detail the nervous system dysfunctions observed during the program of high altitude (38 000 ft) oxygen controlled indoctrination at Maxwell Field the severe symptoms observed in a small proportion of the 40,000 individuals studied occurred not only during the period of great change in atmospheric pressure, but also after exposure to high altitude and even after return to ground level

The duration of consciousness at altitudes up to 32,000 ft after

interruption of the oxygen supply was studied by Mackenzie and others (1946) At 26,000 ft, nine out of 10 men were helpless within five minutes 'The average time to helplessness was 220 seconds For each 1,000 ft increase in altitude between 26,000 to 32,000 feet, the duration of useful consciousness decreased by approximately 20 seconds" Hoffman, Clark, and Brown (1946) report the results of similar studies and correlate the duration of consciousness in anoxia at high altitudes with the associated blood oxygen saturations Experimentally induced changes in the oxygen capacity of the blood modify tolerance to altitude when the maintenance of useful consciousness is used as the criterion (Hall 1949)

Interesting studies of the effect of anoxic anoxia on the central nervous system as revealed by the electroencephalogram have been reported on the rat by Kessler, Hailman, and Gellhorn (1943) and by Engel, Webb, and Ferris (1945) on man Significant changes in the records obtained were demonstrable in human subjects at altitudes of 10,000 ft 'The degree of frequency change at 39,000 feet breathing 100 per cent oxygen with the constant flow system was the same as that found at 10,000 feet breathing air Acute alcoholic intoxication of a degree likely to be experienced by most healthy individuals drinking socially provoked electroencephalographic changes roughly equivalent to those found at 16,000 feet Severe intoxication produced more marked changes Reduction of blood sugar to levels of 44 to 49 mgm % also provoked changes in the electroencephalogram roughly equivalent to that seen at 16,000 feet' From similar studies of men subjected to hypoxia Prast, and Noell (1948) have detected a frequency change that precedes marked mental disturbances at an altitude of 25 000 ft, by at least 60 seconds in normally reacting subjects

At altitudes of 6,000 m or above, eye-hand coordination shows considerable deterioration (Muido, 1946) Functional and organic injuries to the nervous system induced by anoxia in laboratory animals have been reported by Ikemune (1940) and by Altmann and Schubothe (1942)

The threshold for thermal pain is not significantly modified by breathing 10% oxygen, according to Stokes, Chapman, and Smith (1948)

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Fenn (1946) conclude that acapnia and anoxia are additive rather than antagonistic in their effects on contrast discrimination and steadiness At each altitude there exists an optimum alveolar air composition for each type of performance, optima that may differ for different types of performance "Performance impairment in most individuals breathing naturally at air-breathing altitudes is essentially a matter of anoxia alone"

j Effects on the eye The eye has been shown to be extremely sensitive to anoxia, and the importance of good vision, especially scotopic vision to airplane combat has furnished the stimulus for a large volume of experimental study of the eye at different partial pressures of oxygen For general discussions of the subject, the reader is referred to an article on "Ophthalmic aspects of acute oxygen deficiency" by McFarland, Evans, and Halperin (1941), to Gellhorn and Hailman's (1943) article on "The effect of anoxia on sense organs," devoted mainly to the eye, and to Hartline's (1946) "Problems of visual physiology during the war"

Dark adaptation is definitely impaired by anoxic anoxia at partial pressures of oxygen where other sensory tests have failed to show reliable changes (McFarland and Evans, 1939) The authors state "However, these effects are probably of no great practical significance in relation to night blindness in a pilot until altitudes of approximately 10 000 to 12,000 feet are attained" The opinion is expressed "that the changes are not concerned with the photochemical substances of the retina but with the neural elements of both the retina and the central nervous system" McDonald and Adler (1939) induced an anemic anoxia in their subjects by the inhalation of a mixture of equal volumes of nitrogen and of air The rod and cone thresholds were raised equally in this state of anoxemia but the rate of dark adaptation was unaltered The impairment in the visual thresholds of both rods and cones induced by vitamin A deficiency and by anoxemia were additive and therefore the lesions in the two cases are probably different Anoxemia induced by CO poisoning is similar in its effect on the eye The formation of carbon monoxide hemoglobin has the same effect on visual thresholds as an equal loss of oxyhemoglobin at high altitudes (McFarland, Roughton, Halperin,

and Niven 1944) Inhalation of CO from a cigarette caused an appreciable increase in the percentage in the blood of carbon monoxide hemoglobin These changes in visual threshold are all reversible by oxygenation Dvořák, Kopecky, and Mikula (1948) reported a rise of 9% in the visual threshold for white, red, and green lights at a pressure of 355 mm of Hg (6,000 m) as compared with normal atmospheric pressure (seen in abstract only)

Other papers on the same general problem have been published by McFarland and Halperin (1940) and McFarland, Halperin, and Niven (1944, 1945) In 1940 McFarland and Forbes showed that hypoglycemia as well as anoxia affect light sensitivity of the retina, probably by slowing oxidative processes 'Consequently, the effects of anoxia may be ameliorated by giving glucose and the effects of hypoglycemia by inhaling oxygen' The relation between anoxia and brightness discrimination has been discussed by Hecht *et al* (1946) and the respiratory effects upon visual threshold by Wald *et al* (1942), both senior authors being specialists in visual physiology Gellhorn and Hailman (1944) observed a parallelism between changes in visual function under anoxia and changes in the electroencephalogram A rise in retinal arterial pressure occurs at low altitudes and then slowly disappears (Duguet and Bailliart, 1947) A fall in retinal arterial pressure under anoxia is characteristic of non-tolerant subjects Anoxia also prolongs the latent period between stimulus and visual after image (McFarland, Harvich, and Halperin, 1943) and acts as a mydriatic (Hoorens, 1948)

The occurrence of a restriction in the visual field at altitude was noted by Wilmer and Berens in 1918 Smith, Seitz, and Clark (1946) showed quantitatively the development of the peripheral blind area (*angioscotomata*) at partial pressures of oxygen equivalent to an altitude of 10,000 ft According to Houston (1947a) scotomata can also be produced by aeroembolism within the retinal arteries At ground level Simonson, Brozek, and Keys (1948) did not find that high carbohydrate meals, as compared with 'standard meals and high fat meals, were beneficial in their effects on visual performance and fatigue during appropriate work involving eye hand coordination

k Acclimatization to anoxia The immediate responses and ad

justments of the body to anoxic anoxia have been briefly outlined above. Those adjustments that occur only slowly over a period of time at altitude or during intermittent flights to high altitude constitute acclimatization to anoxia. The reality of such acclimatization has been well established. Its features have been discussed by Haldane (1927), by Gemmill (1941), by Houston (1947b), and by Grandjean (1948). Comprehensive investigations of this phenomenon have been reported by Merény, Korényi, and Gordon (1944), Houston (1946b) and Houston and Riley (1947) on man, and by Reynolds and Phillips (1947) on the rat. The latter authors observed a regression of adaptation on interruption of altitude exposures, leaving the animals less tolerant to anoxia than unexposed animals.

Monge (1948) has published an interesting and scholarly book on acclimatization in the Andes, using mainly the historical approach to the subject. The documentary evidence discussed testifies to the importance of "climatic aggression" in the development of Andean man. Whether the abstention when young from the use of fat, honey, chili, salt, and vinegar, according to the records, contributed to the tolerance of Andean man to the high altitudes at which he lived (up to 17,000 ft.) may be questioned in view of recent experimental work to be discussed below.

Keys, Matthews, Forbes, and McFarland (1938) studied the individual variations in a group of 10 men in the ability to acclimatize to high altitude. They found that youth, slow pulse, low-normal blood oxygen capacity, low alveolar oxygen pressure, high alveolar carbon dioxide pressure and high alkaline reserve at sea level are favorable to acclimatization at high altitude.

Perhaps the most commonly observed and the most significant factor in acclimatization to anoxia is an increased oxygen carrying power of the blood, due to increased content of hemoglobin and of erythrocytes, accompanied by an increase in myohemoglobin in some muscles (Hurtado, Rotta, Merino and Pons, 1937, Poel, 1949), but with no increased affinity of hemoglobin for oxygen (Hall, 1936, Aste-Salazar, and Hurtado, 1944). Whether or not anoxia increases myohemoglobin concentration in a specific striated muscle, according to Poel, depends on the change in activity of that muscle due to the effect of the anoxic environ-

ment Poel worked with rats Working with dogs, Bowen (1949) obtained results indicating that exposure to a simulated altitude of 18,000 ft causes no increase in the myohemoglobin content of the gastrocnemius and soleus muscles in contrast to the response of the blood hemoglobin Bone marrow studies by Merino and Reynafarje (1949), on human subjects living at 14,400 ft altitude revealed hyperplastic changes, involving the erythroid cells much more than the myeloid cells Recent evidence of increased hematopoietic activity during acclimatization to altitude has been reported by Hurtado, Merino, and Delgado (1945) and Lewis *et al* (1943) in experiments on men, by Stickney and Van Liere (1942b) in studies on the dog, and by Bancroft (1949) on the rabbit

Ruff and Strughold (1942) have recorded the changing blood picture of a man who stayed for two months at altitudes varying from 13,000 to 23,000 ft The hemoglobin content of the blood rose from 18 3 to 24 5% and the red cell count from 5 64 to 8 32 millions per mm³ On return to sea level these values returned to normal, the hemoglobin content within one month and the red cell count some time later Other references of the same import are, on men, Sankaran and Rajagopal (1938), and Vannotti and Markwalder (1939), and, on guinea pigs, Gordon and Kleinberg (1937) and Jensen and Alt (1945) Continuous residence at an altitude of 11,000 ft (Smith, Belt, Arnold, and Carrier, 1924–25) increases in man the volume of plasma as well as of corpuscles

In the dog according to Stickney and Van Liere (1942a), The usual delay in gastric emptying time produced by anoxia has been found to be gradually reduced in every case' during discontinuous exposure to pressures simulating altitudes from 12,000 to 18,000 ft One interesting phase of acclimatization to altitude, according to Van Liere, Stickney, and Northup (1948), in experiments on dogs is the return of blood sugar to normal levels

ACCELERATION

Acceleration is not a factor in climatic stress, but it is a hazard in military and naval aviation and it may not be out of place to

consider it briefly here Wood, Lambert, Baldes, and Code (1946) have discussed the effects of acceleration on the cardiovascular system increased weight of blood and tissues, decreased blood pressure at head level, which are the key to the orderly pattern of changes in ear opacity, ear pulse and heart rate The function of the cerebrospinal fluid in protecting the cerebral circulation against radial acceleration was studied in cats by Rushmer, Beckman, and Lee (1947) The biochemistry of gravity shock, induced in rabbits by suspending them in the vertical position, was found by Nastuk (1947) to depend upon a circulatory deficiency leading to tissue hypoxia 'The data suggest that tissue hypoxia produced by suspension of the rabbit results in loss of energy rich phosphate bonds of muscle, and in impairment of the mechanism which generates these bonds Under these conditions, production of energy from carbohydrate metabolism may fall to levels insufficient to sustain the animal" Protective aids against exposure to acceleratory force were tested by Britton, Pertzoff, French, and Kline (1947)

The effect of food and drink was found by Clark and Jorgenson (1945a, b) to increase G tolerance in human subjects "The similarity in results between the ingestion of water and milk and food largely rules out hyperglycemic effects Fluid and food ingestion increases cardiac output without evoking vasomotor mechanisms or displacement of blood from somatic tissues to the visceral organs increase in intra-abdominal pressure remains as the only explanation of G protection' In another report, Clark, Gordiner, McIntyre and Jorgenson (1945) present the results secured on three human subjects on the effects of hyperglycemia, induced by sugar ingestion, and of hypoglycemia induced by insulin injection on G tolerance Slight effects (0 2 G) only were noted The trend toward a slight positive effect of blood sugar con centrations on G tolerance suggests the possibility that extracellular sugar may, by acting as a substrate in anaerobic glycolysis, alleviate somewhat the brief brain and retinal anoxia associated with the acute brain anemia induced by blood displacement during radial acceleration"

In the last year or so there have been many reports on the physiological response to acceleration and on protective methods,

of which the following are samples protection against acceleration by CO_2 inhalation (Van Middlesworth and Kline, 1948) and by abdominal pressure (Britton, 1949, Britton and French, 1949), effect of body position on incidence of motion sickness by Manning and Stewart (1949), fluid shifts during exposure to acceleration by Stauffer and Hyman (1948), acceleratory effects on renal function (Silvette and Britton, 1948) and on respiration (Lombard, Roth, and Drury, 1948).

EFFECT OF ALTITUDE ON NUTRIENT REQUIREMENTS

There seems to be little reason to expect, and scanty evidence to support, a belief that altitude and its associated low oxygen tension will disturb the nutrient requirements of man The low oxygen supply at altitude will depress, rather than stimulate, metabolic processes, and, even more surely than a hot humid environment, will discourage the performance of muscular work and lower the capacity for work Bronshteĭn (1944) has reported that hypoxemia lowers the level of ascorbic acid in the blood of guinea pigs and hastens the development of scurvy on a normal diet Borsuk (1949), whose report has already been referred to (see page 117), has confirmed these observations of Bronshteĭn

The extensive dephosphorylation of the tissues that Greig and Govier (1943) have demonstrated in animals exposed to anemic anoxia or to anoxic anoxia may, according to Govier (1944), extend to dephosphorylation of cocarboxylase, which may be very largely involved and leads to a rise in the blood thiamine and probably an increased spill over into the urine The end result might be an increased thiamine requirement Gusman *et al* (1945) have noted a rise in the pyruvic acid content in the blood of aviators, somewhat in proportion to the altitude attained, an observation that ties in with the findings of Govier The problem deserves further study

Hyperventilation may increase the water requirements by expediting the loss of water from the respiratory passages The increase may not, however, be large (Marshall, 1946, Matthews, 1932–33)

EFFECT OF DIETARY MODIFICATIONS ON THE TOLERANCE TO ANOXIA ANIMAL EXPERIMENTS

1 Fasting A critical test of the question whether tolerance to anoxia can be modified by diet, is to compare fasting with feeding of a well balanced diet This was done with rats by Leblond, Gross, and Laugier (1943), who found that fasting for 12 to 24 hours definitely depressed resistance to anoxia, but that fasting prolonged beyond this period was accompanied by a recovery of resistance What may be a second report of the same experiments was published by Laugier and Leblond (1943), with the same outcome In the experience of Smith, Oster, and Toman (1944), the under feeding of cats increase greatly their resistance to low oxygen tension

The livers of fasted rats when exposed to an atmosphere of nitrogen for 70 minutes showed a 75% depression in oxygen up take, while the livers of fed rats showed only a 25% depression (Craig 1943) Whether the glycogen content of the liver, or some other factor in the experiment, determined the results was not established Mylon and Wilhelmi (1945) confirmed Craig's results on rats, using subsistence on a low protein high carbohydrate diet in comparison with fasting On this diet, the liver glycogen is high (4 to 7%) and may be an important contributing factor to increased resistance to anoxia Van Middlesworth (1944) has reported that liver glycogen of rats is reduced in anoxic anoxia even in the presence of excess blood sugar induced by sugar feed ing The marked hyperglycemia and glycosuria of glucose-fed rats under reduced oxygen pressure, accompanied by a diminished cardiac and liver glycogen, has been called a condition of "anoxic diabetes" by Van Middlesworth (1946) Under the same conditions adrenalectomized rats exhibit a hypoglycemia (Van Middlesworth, 1944)

2 Carbohydrate feeding The effect of carbohydrate feeding on the resistance of animals to anoxia was studied as early as 1907 by Packard Using minnows (*Fundulus heteroclitus*) as subjects and producing anoxia by placing the fish in unaerated sea

water, he showed clearly that intraperitoneal injection of fructose, glucose, or maltose, but not sucrose or lactose, definitely prolonged life during oxygen lack On the other hand, the survival of Fundulus fasted prior to anoxia was not improved by the feeding of a high-protein food, mussels The favorable effect of the monosaccharides is attributed to a type of anaerobic oxidation promoted by sugar, in which the sugar acts as a hydrogen acceptor in accordance with a theory of oxidation proposed by Mathews (1905) Many years later, Selle (1944) secured evidence that the marked tolerance of young rats to anoxia is due primarily to an anaerobic source of energy and that this source of energy is replenished by glucose administration and depleted by insulin Following decapitation of the young rat, gasping of the isolated head may continue for 30 minutes or more The injection of glucose into the rat prior to decapitation increases the survival of respiratory activity of the isolated preparation by 30%, while injection of insulin results in a slight to moderate reduction in the duration of the aerobic gasps, an effect that can be counteracted by glucose Fazekas and Himwich (1943) have studied further the anaerobic development of energy from carbohydrate cleavage for the maintenance of cerebral function

Britton and Kline (1945), working with rats, reported that glucose administration, especially parenteral, improves greatly the resistance of rats to low barometric pressure Fully fed animals survived somewhat better than fasted controls, while insulin markedly reduced the ability to withstand anoxia An item of incidental importance in this report is the observation that survival time under anoxia is inversely related to environmental temperature For a 10°C drop, survivals were increased about 50% Smith and Oster (1946) noted with cats also that insulin decreases resistance to hypoxia, while decreasing posthypoxic hyperglycemia, but they observed no general correlation between anoxic tolerance and post-hypoxic-hyperglycemia According to Himwich, Fazekas, and Homburger (1943), hyperglycemia protects anoxic infant rats but not adults

Studying the mechanism for the maintenance of life in the newborn rat during anoxia, Himwich *et al* (1942) injected the animals with various substances modifying carbohydrate metabolism

and noted the survival times after exposure to an atmosphere of nitrogen Iodo-acetate and insulin shortened the survival period, while glucose prolonged it considerably, demonstrating the importance of glucose in serving as a source of energy under anaerobic conditions

Busing and Kauff (1942) observed a slightly favorable effect of a pre-feeding of fructose on the tolerance of rabbits to low air pressures Prior observations of Busing, and of Forster (1940) had indicated a favorable effect of massive doses of vitamin B_1 on rabbits exposed to low oxygen tensions These findings interested Busing and Kauff in the effects of sugar and of thiamine on the blood creatine and creatinine, in view of the intimate relationship of creatine phosphate in the carbohydrate metabolism, particularly in muscle It was found that on exposure to diminished pressure equivalent to altitudes of 9 500 to 10,000 m , the total creatinine of the blood increases during the first half-hour, and then falls, but not to its pre exposure level A pre-feeding of fructose increases this elevation of total creatinine, while a pre feeding of vitamin B_1 depresses it The whole picture conforms with the theory that anoxia disturbs the oxidation of carbohydrate, the disturbance being aggravated by sugar feeding and ameliorated by administration of vitamin B_1

But the results of glucose administration on tolerance to anoxia in laboratory animals have not been concordant Dohan (1942) tested the effects of high carbohydrate and high fat diets on the survival of adult rats exposed for 15 5 to 23 hours to air pressures ranging from 380 to 235 mm Hg Three of 8 rats fed the high carbohydrate diet and four of nine fed the high fat diet survived until the end of the experiments Exposure of the rats for more than two days to low pressures produced a significant increase in adrenal weight and a significant decrease in the weight of thymus and testes, but again no differential diet effects were noted The authors state "However, in connection with the lack of effect of diet in our experiment it is well to point out the long time intervals between feedings" The rats were tube fed a daily caloric supply adequate for the maintenance of body weight at atmospheric pressure but only in the intervals between low-pressure exposures

In a series of five experiments reported by Ivy, Friedemann, and Grodins (undated report), 170 male albino rats were exposed to lethal degrees of anoxia, one half of the animals being fed 1 gm of sucrose the hour before exposure No protective effect was observed there was 41% survival of the treated animals and 46% survival in the controls The failure of carbohydrate to prolong life may be due to the amount given, the lack of detectable response of a very anoxic-resistant animal, or the masking of any favorable effect of carbohydrate upon the R Q by the increased need of oxygen in increased metabolism Langwill, King and MacLeod (1945) also failed to notice a beneficial effect of 2 gm of sucrose given to adult male rats prior to exposure to moderate degrees of anoxia In these experiments anoxia induced a marked diuresis and an increased alkalinity of the urine

3 PROTEIN AND FAT FEEDING The effect of a dietary protein supplement (5 gms of raw horse meat) on the survival of nearly mature adult rats when exposed to severe anoxia (5% oxygen, 95% nitrogen) was studied by Langwill, King, and MacLeod (1945) The basal diet was a commercial mixed feed containing 26 2% protein and 5 4% fat The meat supplement appeared to exert a slight detrimental effect on tolerance to anoxia six of 15 rats on the unsupplemented diet survived, while only two of 15 survived on the supplemented diet However, application of the X^2 test, fails to establish any significant effect of the protein supplement (P=0 17) Ivy, Friedemann and Grodins (undated) reported a somewhat similar test with larger numbers of rats in which a protein free and a high-protein diet (48%) were compared, the results indicated clearly (P=ca 0 017) by the same statistical test, a less favorable effect on survival to anoxia of the high protein diet But whether the difference is due to a variable protein intake or to a variable carbohydrate intake is not clear In neither case is the total caloric intake given, although this may be a factor in tolerance to anoxia, as indicated in the discussion above

Evidence of the effect of fat feeding on tolerance to anoxia is conflicting and inconclusive With eight and nine adult male rats to a group, Dohan (1942) was unable to detect a difference in this respect between a high carbohydrate and a high fat diet, the protein content remaining constant On the other hand, the ex-

periments of Hove, Hickman, and Harris (1945), also involving small groups of rats, indicate that even 12% of fat in the diet of animals exposed to severe anoxia equivalent to about 170 mm Hg total air pressure is definitely detrimental to survival But again caloric intakes are not recorded

4 VITAMIN SUPPLEMENTS The hypertrophy of the adrenal gland induced by anoxia suggests that anoxia disturbs the metabolism of ascorbic acid, and that the physiological effects of anoxia may be alleviated by ascorbic acid administration It is well established that ascorbic acid is intimately involved in adrenal function, the ascorbic acid content of the gland being extremely high In fact, the vitamin was first crystallized from this source From experiments on human subjects that will be discussed later, Krasno, Ivy, Atkinson, and Johnson (1943) received the impression that exposure to altitude causes a retention of ascorbic acid in the body, which is later released during intervals between exposures They investigated this possibility by exposing guinea pigs for 12 hours to a simulated altitude of 18,000 ft, after intramuscular injection of 100 mg of ascorbic acid Control animals, similarly injected, were not exposed to diminished pressure Two to four hours after decompression of the test group, the plasma ascorbic acid level in both groups was determined and a few hours later all animals were sacrificed The ascorbic acid content of both blood plasma and muscle tissue was higher in the exposed animals These experiments were considered as confirming the suggestion obtained from the observation on men, though in themselves they fail to indicate any possible favorable effect of ascorbic acid administration on tolerance to anoxia

Experimenting with an animal, the albino rat (male and nearly full grown), able to synthesize ascorbic acid in its tissues, Langwill, King, and MacLeod (1945) studied the excretion of the vitamin in the urine under conditions of mild anoxia induced by exposure at atmospheric pressure to a gas mixture containing 7 7% of oxygen and 92 3% of nitrogen for two or three hours The subsistence diet was Purina Dog Chow alone or with supplements of raw horse meat or sucrose Exposure to anoxia diminished the output of ascorbic acid in the urine in all groups and experiments, somewhat in proportion to the concomitant rise in urine

pH The nature of the dietary supplements seemed to have no effect on the magnitude of this reduction in urinary ascorbic acid Although the suggestion is not directly made by the authors of this report, one may infer from their discussion that, if the decrease in urinary ascorbic acid in anoxia may be interpreted as the result of a retention of the vitamin in the tissues, it may be considered a protective mechanism available to the animal against agents or conditions that suppress respiration of the central nervous system In a brief note, Peterson (1941) reported that intraperitoneal administration of ascorbic acid (or of methylene blue) increased the resistance of rats and mice to low oxygen tensions, presumably, according to the author, by making oxygen more available to the tissues

Hailman (1944) studied the effects of some of the water soluble vitamins, particularly riboflavin, in modifying the disturbances in tissue functions and in intact animals induced by anoxia The experiments were inspired by published evidence (Dietrich and Pendl, 1937) "that perfusion of the isolated frog heart with low oxygen concentrations causes a weakening of the contractions which are promptly restored by physiological oxygen pressure or by adding a minute quantity of riboflavin to the perfusion medium" Hailman failed to confirm this anti anoxic effect of riboflavin, but obtained positive results with this vitamin in preventing the anoxic effects on the spontaneous rhythmical contractions of smooth muscle from the frog's esophagus Large doses of the B vitamins to male rats did not, in his experience, prevent *hypertrophy of the adrenal cortex when the animals were subjected to a pressure of 294 mm* Hg for 48 hours "In a series of 12 experiments on seven dogs it was found that riboflavin 1 mgm per kgm given intravenously, prevented the depression of the linguo maxillary reflex during the inhalation of low oxygen mixtures" Wolff and Karlin (1947) failed to find, in mice receiving a normal diet, any correlation between survival to low oxygen tension and the riboflavin content of the liver

Rabbits exposed to air pressures equivalent to altitudes of 9,500 to 10,000 m, show some slight favorable effect of a pre feeding of fructose, and a further, and slight, favorable effect of thiamine feeding, according to Busing and Kauff (1942) The increased

tolerance afforded by the latter supplement is presumed to relate to the proper metabolism of the fructose supplement. Iwatare (1944), noted a favorable effect of vitamin P, but not of thiamine, riboflavin, and ascorbic acid, on the survival of mice exposed to a pressure of 205 mm Hg equivalent to an altitude of 10,000 m, or 32,800 ft. In the absence of a statistical analysis of differences in mean group survival times, it is impossible to draw positive conclusions from the evidence presented.

It is known that resistance to reduced atmospheric pressure is decreased by the administration of thyroid material and it is suspected that some of the vitamins exert an anti-thyrogenic effect. Hence, Charipper, Goldsmith, and Gordon (1945) performed some experiments "to ascertain whether an abnormal vitamin intake, deficiency or overdosage, would influence the resistance of rats exposed to lowered barometric pressures ... ." Dietary concentrations of riboflavin, pyridoxine or pantothenic acid that were definitely deficient were without demonstrable effect on tolerance to decreased pressure, as were also supplements of thiamine, ascorbic acid, and calcium pantothenate to such deficient synthetic diets. On the other hand, a diet deficient in thiamine seemed definitely to increase tolerance, an effect that could be obliterated by the administration of 1 mgm. of thiamine shortly before low-pressure exposure, a most anomalous result. A restricted intake of a complete diet also favored increased resistance to anoxia. An increase in resistance to anoxia in thiamine deficiency was also observed with cats by Smith, Oster, and Toman (1944), but the effect may have been caused by a decreased intake of food, which in itself was shown to be effective. If the tissue anoxia induced by hemorrhagic shock is analogous to that induced by low atmospheric pressure, the findings of Govier and Greer (1941) on dogs are at variance with those just discussed. These authors observed an increase in blood keto acids (which may include pyruvic, acetoacetic, α-ketoglutaric and oxaloacetic) in hemorrhagic shock; on thiamine administration the blood keto acids decreased and the survival time was prolonged.

From the known functions of some of the B vitamins in oxidation-reduction enzyme systems, one might expect that under conditions of severe anoxic anoxia, part of the coenzyme containing

the vitamin would be trapped in the reduced state because of lack of oxygen (Calder, 1948) In such a situation the administration of a vitamin, such as nicotinic acid, "might augment the available supply of coenzyme and thus, in effect, correct this induced deficiency" The accumulation of an oxygen debt in severe muscular work may be another instance of the same situation In this connection it may be noted that Frankau (1943) has reported a series of experiments at ground level in which a supplement of nicotinamide to the "normal" diet of physically fit young men resulted in increased efficiency in carrying out a severe test involving both physical effort and coordination Under conditions of severe oxygen deficiency, at pressures ranging from 420 to 110 mm of mercury, Decharneux (1933) found with guinea pigs that 1 mg of the diethylamide of nicotinic acid (coramine) per 100 gm body weight injected intramuscularly deferred the symptoms of anoxia (Cheyne Stokes respiration, convulsions and eventual death) Calder (1948) has confirmed the anti-anoxic value of nicotinic acid or its amide on rats weighing from 125 to 150 gm The treated animals (1 mg intraperitoneally) withstood lower pressures and exhibited less severe tachypnea at the same low pressures than did the untreated controls Statistical analysis of the data ruled out the vitiating effect of the uncontrolled factors in the experiments

The observations of Hove, Hickman and Harris (1945) on the favorable effect of α tocopherol on tolerance to decompression seem clear-cut except for the possible disturbing effects of variable food intakes, the data for which were not reported Given orally in physiological quantities to adult rats, the natural mixed tocopherols induced an increased survival to anoxic anoxia averaging 80% as compared with controls on an E-low and low fat diet The respective diets were fed for two to three weeks prior to decompression Injection of massive single doses of d α tocopherol phosphate into guinea pigs on a rabbit chow diet greatly increased the survival time to anoxia, but no such effect was secured with rats

5 Carrot feeding In 1938 Campbell discovered that rats subsisting on a sole diet of carrots, either raw or boiled, could withstand anoxia much longer than on a normal diet, although

losing weight The correlation between weight loss and survival was not close, however The factors underlying the beneficial effect of a carrot diet are considered by Campbell (1949) to be the low-protein content, the presence of fiber, the presence of glutamine and of some unknown factor The different protein-ogenous amino acids were found to have variable effects on survival in low pressures On the basis of his extensive experiments on rats, not readily interpretable, nor very consistent among themselves, Campbell offers the following comment "On the above evidence, suitable articles of diet for subjects exposed to the effects of oxygen want due either to disease or to high altitude are zein (but not whole maize), carrots, parsnips, beetroot, apples, bananas, starch, glucose, fat (lard), vitamins, and salts Gelatin and gluten (flour) might be used also in very moderate quantity and milk in small quantity"

This seems to be a rash extension to human nutrition of results obtained upon a laboratory animal, but has been quoted with approval by the British Medical Journal (Editorial, 1940), from which a more conservative attitude might be expected

Campbell's results have been amply confirmed on the rat by Wetzig and D'Amour (1943), Nelson, Goetzel, Robins, and Ivy (1943), Langwill, King and MacLeod (1945), and possibly by others The results of the latter authors are particularly noteworthy They found that when the consumption of dog chow by their experimental animals was regulated iso-calorically with the consumption of dehydrated carrots, animals on the two diets survived about equally well in severe anoxia (30 min at 40,000 ft) under some conditions of feeding, 'but in other tests, with an opportunity for adaptation by repeated exposures and more gradual ascent, there was evidence of added protection as a result of the carrot diet The increased alkalinity, high potassium content and low protein content of the carrot diet afford a tentative basis of accounting for the increased tolerance" The assumed favorable effect of a high potassium intake is based upon the findings of Dixon (1940) that, in cerebral cortex tissue *in vitro*, the addition of excess potassium ions markedly inhibits the production of lactic acid and the destruction of glucose resulting from oxygen deprivation

6 MINERALS In experiments at the Naval Medical Research Institute (1945) on the self-selection of water and salt in rats rendered anoxic by decompression at altitude, it was found that the voluntary intake of water and of salt was not altered by acute or chronic anoxia The usually observed increase in heart rate in guinea pigs on decompression is lowered by administration of calcium salts, according to the report of Geppert, Peña, and Schaefer (1944) Other evidence of a favorable effect of calcium on resistance to anoxia has been presented by Di Macco (1945), using guinea pigs also

The well established stimulation to erythropoiesis induced by the cobaltous ion was found by Dorrance and others (1943) to be associated in rats with an increased work performance under conditions of anoxia, though even in the small dosage used, some untoward effects on the animals were noted

EFFECTS OF DIETARY MODIFICATIONS ON TOLERANCE TO ALTITUDE HUMAN EXPERIMENTS

1 CARBOHYDRATE FEEDING In 1940, Boothby, Lovelace, and Benson from theoretical considerations of the effect of high altitude on the human body, estimated that an aviator breathing the ambient air, and unacclimatized to altitude, can withstand an elevation of 15,000 ft more than an hour one of 20 000 ft, less than an hour Since more oxygen is needed to burn fat than to burn sugar to CO_2 and H_2O (and in fact more oxygen per calorie of energy produced), it was estimated that a high carbohydrate diet is capable of raising the aviation ceiling 1,000 to 2,000 ft From considerations of the relation of the respiratory quotient to alveolar oxygen tension, Grodins (undated) computed that the aviation ceiling may be 2,000 to 5,000 ft higher when the R Q is 1, that of pure sugar combustion, than when the R Q is 0 7, that of the combustion of pure fat

The fact that sugar is the main (or sole) source of energy for the brain and that the brain responds adversely to hypoglycemia (as it does to anoxia) is merely another reason for favoring carbohydrate food in aviation Polonovski (1940) observed that the in

gestion at high altitude of 80 gms of sugar helped in combating fatigue and the tendency to somnolence A sugar drink, fortified with minerals, was found by Blasius and Bauereisen (1942) to compensate for the changes in carbohydrate metabolism induced by anoxia Improvement in tolerance was also revealed by a writing test, by the clinical behavior and by the ability to tolerate longer an altitude of 7,000 m The improvement in tolerance seemed greater for those subjects, thirteen in all, whose tolerance to altitude was initially greater

The relationship between the consumption of carbohydrate foods and tolerance to altitude was thoroughly studied during the war period in several laboratories throughout the country, generally in projects sponsored by the Committee on Medical Research of the Office of Scientific Research and Development The results obtained are in good agreement and furnish a most impressive solution of the problem

King, Bickerman, and associates (1945) have reported the results of a very thorough study of the effect of the composition of pre flight and in flight meals on tolerance to altitudes of 15,000 to 17,000 ft The acquired tolerance was measured by 13 separate tests, but in the interpretation of the data, two tests only were selected for primary emphasis, i e, the block placement (University of Minnesota) test and angioscotoma records, as criteria of psychomotor performance and of corticoretinal function (chiefly peripheral vision), respectively The report contains illustrative records comparing 6 5 hour fast with breakfasts and lunches carrying 600 to 800 calories and containing high proportions of carbohydrate, protein, or fat Diet groups of 10 men each were employed Fasting beyond four to five hours was found to be least favorable to altitude tolerance and high-carbohydrate meals most favorable Dietary protein increments from 10 to 20, 30, and 40% of the total calories were accompanied by decrements in altitude tolerance Fats were intermediate in their effects In terms of equivalent altitude (or gain in "ceiling"), carbohydrate showed a saving over protein of approximately 2 000 ft in the 12,000 to 17,000 foot range (King, 1946) The authors are careful to state "These findings pertain to immediate pre-flight and inflight feeding and *do not* connote departures from normal re-

quirements or good practices relative to the food intake *as a whole*." The authors, in commenting on the advantages of carbohydrate foods, emphasize the importance of maintaining the glycogen reserves of the body at altitude. In a private communication, King expresses the opinion that the evidence of these experiments favors the view that carbohydrates, as compared to protein foods, also afford some protection against syncope at altitude. In a later publication, King, Bouvet *et al.* (1945), show that preflight carbohydrate meals hold their advantages for six hours ov high protein high fat meals. In all of these tests the distortio in the test meals of the proportions of the various organic nutrient was rather extreme.

McFarland, Halperin, and Niven (1945) found that anoxia (simulated high altitude) impairs the differential intensity thresholds for vision at low brightness levels, and that the ingestion of 50 gms. of glucose during exposure to low oxygen tension results in a considerable decrease in the impairment due to anoxia. In three subjects, this decrease amounted to 42, 25, and 48%. Under ground level conditions, sugar ingestion does not increase visual sensitivity in dim light. At altitude, the anti-anoxic effect of sugar on this function parallels the concentration of sugar in the blood, and seems to depend upon blood sugar level. From the work of King and of McFarland and their associates, one may conclude that anoxia restricts the field of peripheral vision and depresses visual sensitivity in dim light, and that with prior sugar feeding both impairments in visual efficiency are considerably lessened.

A possible adverse effect of sugar feeding prior to altitude ascent is pointed out by D'Angelo (1946b) who noted that the ingestion of glucose at moderate altitude "can cause the development [within a 10 hour period] of secondary hypoglycemic reactions similar to those induced at ground level, and sufficiently marked to affect adversely well-being and efficiency in flight." While sugar tolerance is not appreciably altered at moderate altitude (8,000 to 10,000 ft.), "There is suggestive evidence that the homeostatic mechanism controlling blood sugar level is affected."

The experiments of Eckman, Barach, and others (1945), while involving fewer subjects and different criteria of tolerance, were

similar in purpose and in outcome to those of King *et al* The criteria in this case were changes in blood gases, in the composition of alveolar air and in psychomotor and psychological performance Unfortunately the validity of average changes in test measurement was not tested statistically, contrary to King's practice The prescribed test meals contained 750 cals each and were high in carbohydrate or high in both protein and fat In some tests the subjects were permitted to choose the quantity and type of food consumed Again, there was an indicated gain in altitude tolerance on the high-carbohydrate meal over the high-protein high fat meal, estimated to range from 1,000 to 2,000 ft at an altitude of 17,000 ft It is important to note, however, that when the subjects were permitted to choose their pre-flight meals their altitude tolerance was decreased compared with the high-carbohydrate meals by only some 500 ft The authors also comment on the fact that, in so far as this increase in altitude tolerance induced by carbohydrate food is traceable to an elevation in the respiratory quotient, it would not be expected to appear under conditions of oxygen inhalation

At the Smoky Hill Army Air Field at Salina, Kansas, Green, Butts, and Mulholland (1945) reinvestigated the relationship of anoxia susceptibility to diet, using 50 subjects and exposures of two hours to a simulated altitude of 17,000 ft without oxygen The two pre flight meals tested contained 69% carbohydrate, 21% fat, and 10% protein in one case and about equal proportions of these classes of organic nutrients in the other The tests employed for the evaluation of anoxic effects were a single dimensional pursuit test, a vision demonstration card test, an arithmetic test, a cube-placing test and an angioscotomata test Statistical methods were used in interpreting the data secured The advantages of the high carbohydrate meal were evident generally, although the magnitude of the indicated diet differences (ranging from 4 to 50%) and the degree of confidence in their reality differed Contrary to the experience of King and associates, the angioscotomata test was the least sensitive to diet effects In commenting on their findings, the authors say—

"In the operation of aircraft small differences in mental functioning and psychomotor co ordination may produce errors in

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In the operation of aircraft small differences in mental functioning and psychomotor co ordination may produce errors in

judgment and reaction responsible for inaccurate bombing, poor marksmanship or loss of the aircraft

"Consideration of these factors suggests that the arithmetical advantages of high carbohydrate feedings may be indicative of more significant gains to be had in the form of safety and efficiency in flight" Subjective impressions of efficiency generally favored the high carbohydrate meal although it was the less palatable

The authors conclude "Susceptibility to anoxia may be reduced *by the feeding of diets high in carbohydrate prior to ascent The* magnitude of this effect is sufficient to justify its employment in the feeding of personnel engaging in flight under conditions of actual or anticipated lowered oxygen partial pressure'

A different approach to the problem of the relationship of diet to altitude tolerance was taken in the experiments of Riesen Tahmisian and Mackenzie (1946) The distinctive features of their plan were to superimpose beverages containing 80 gms of glucose or simulated drink containing saccharine to a diet of choice, 30 to 50 minutes after the supplemental beverage, the subjects were decompressed to 27,000 ft, where fulminating anoxia rapidly leads to unconsciousness and death, the oxygen masks were disconnected and the time till unconsciousness supervened *was taken as the measurement of the effect* of the supplemental feeding, unconsciousness was revealed by the inability to continue writing dictated ditties Taking the pooled data from 39 tests without glucose and 38 tests with glucose, the prolongation of consciousness induced by glucose feeding averaged 73 5 seconds, representing an advantage of 39% over no glucose The t value of 4 3 testifies to the high significance of the difference At 30,000 ft the advantage of glucose feeding, while significant at the 5% level, amounted to only 17% When the tests are made 60 to 80 minutes after ingesting the test beverages, the sugar advantage *is not evident for trained fliers* but is still highly significant for untrained fliers The authors note in this connection that the protection afforded by sugar against this extreme degree of anoxia parallels the blood sugar level

In emphasizing the importance of their findings, Riesen *et al* point out 'In critical situations such as bail out, loss of cabin pressure, or failure of oxygen systems additional seconds of con

100 gm of glucose had little effect on the phosphate excretion Polonovski (1943) reported some slight effect of sugar, but the excretion of total base in the urine at altitude was not shown by Beyne, Boy, Leduc, and Polonovski (1945) to be consistently modified by pre-feeding with sugar

McFarland and Forbes (1940) have reported some very significant studies on the relationship of alveolar oxygen tension and blood sugar level to visual dark adaptation The former was varied by varying the oxygen concentration in an experimental chamber maintained at about 70°F, with constant ventilation and constant total barometric pressure The latter was varied by glucose ingestion or insulin administration The background of the study is well stated by the authors in the following words

"The functioning of the central nervous system appears to depend upon a continuous and adequate supply of oxygen and glucose When the concentration of either of these substances in the blood is lowered to approximately one-half of its usual level there is significant impairment in cerebral function At one third or one-fourth of the normal level, the individual lapses into coma The effects of mild, intermediate, and severe degrees of anoxia on sensory and mental functions have been extensively studied In the case of hypoglycemia however, only the relatively severe effects have received attention, mostly in connection with the treatment of diabetes and more recently in relation to the insulin shock treatment of schizophrenia"

Using 10 subjects varying in age from 25 to 37 years and measuring light sensitivity with the Hecht adaptometer, both the rod and the cone portions of the dark adaptation curve were elevated by anoxia and by insulin, while the ingestion of glucose (70 to 80 gms) largely counteracted the anoxic effect within six to eight minutes High correlations were demonstrated between changes in the visual threshold (Δ log I) and the alveolar oxygen tension ($r = -0\ 89 \pm 0\ 03$) and between Δ log I and the glucose concentration of the blood ($r = -0\ 87 \pm 0\ 04$) The highest correlation was obtained between Δ log I and the product of alveolar pO_2 (mm Hg) and the sugar concentration of the blood (mg %), with $r = -0\ 96 \pm 0\ 01$ Again quoting the authors

"The experiments reported above lend support to the hypothesis

that both anoxia and hypoglycemia produce their effects on light sensitivity in essentially the same way, namely, by slowing the oxidative processes Consequently the effects of anoxia may be ameliorated by giving glucose and the effects of hypoglycemia by inhaling oxygen In our opinion, the changes may be attributed directly to the effects on the nervous tissue of the visual mechanism and the brain rather than on the photochemical processes of the retina"

2 VITAMIN FEEDING The hope is so frequently entertained by nutritionists, even though it almost invariably ends in disappointment, that vitamins consumed above demonstrated requirements will exert some miraculous effect on body functioning in contrast to the more prosaic nutrients, the proteins, carbohydrates, fats and minerals The hope seems to be based upon the presumption that if a vitamin promotes a given function in the body, more of it should do even a better job This is merely one phase, or one implication, of a theory current in many quarters that there is a wide difference between adequate and optimal nutrition The controversy over the latter theory centers around the proper definition of 'adequate nutrition, but also involves the interpretation of available evidence

In vitamin A deficiency, the light sensitivity of the dark adapted eye is impaired, and this impairment can be removed easily and quickly by dietary administration of vitamin A or of its precursors The prevailing opinion as expressed for example by Rowland and Sloan (1945) and Rose and Schmidt (1947), is that the degree of visual acuity in dim light characteristic of the individual cannot be improved by vitamin A supplementation of an adequate diet Prior evidence to the contrary may be questioned on one basis or another Rowland and Sloan state the situation well "It should be emphasized that true night blindness due to avitaminosis is undoubtedly an extremely rare occurrence in otherwise healthy young men Evidence from other studies shows, moreover, that in the vast majority who have normal night vision, no improvement results from the addition of vitamins to an already adequate diet"

The observation of McFarland, Halperin, and Niven (1945) that anoxia impairs the light threshold for vision in dim light has

been noted above Since this impairment is corrected (partially or entirely) by prior glucose feeding, it seems unlikely that a pre-feeding of vitamin A would also exert an anti anoxic effect, since the relation of sugar and of vitamin A to vision are so entirely different McDonald and Adler (1939) showed the anoxic effect and the vitamin A effect on dark adaptation to be additive King (1943) did not observe a significant disturbance in the concentration of vitamin A in the blood plasma during mild anoxia, the data secured being extremely variable

The effect of ascorbic acid on altitude tolerance in man has been studied in a number of laboratories with rather inconsistent results The experiments of Ivy and associates (see Krasno, Cilley, Boutwell, and Ivy, 1945) at Northwestern University were concerned, among other things, with the effect on human subjects of the degree of ascorbic acid deficiency induced and of the disturbance of the metabolism of the vitamin by mild anoxia Groups of seven to 11 subjects were exposed repeatedly to 18,000 ft without supplemental oxygen, and to 35,000 ft with pure oxygen for one hour The basal diet was adequate and contained about 90 mg of ascorbic acid per day During several weeks of repeated exposure to mild anoxia, the urinary output decreased from 34 mg to 12 mg per day, and the blood plasma level of the vitamin dropped from 0 73 to 0 58 mg % These changes are interpreted as indicative of increased utilization of ascorbic acid in anoxia On exposure of the men to 35,000 ft with oxygen for one hour, the urinary excretion of ascorbic acid and the blood plasma level increased The urinary excretion of total fixed base first increased at altitude, and then decreased, leaving the total output unaltered In interpreting their findings, the authors state

"In view of the role that ascorbic acid plays in cellular oxidation-reduction reactions, its presence normally in a relatively high concentration in the adrenals, and the observation that the vitamin may be depleted by repeated exposure to anoxia, which also depletes body base, it is suggested that liberal quantities of fruit or fruit juices be supplied in the diet of aviators and patients who may be subject to exposure to discontinuous or continuous anoxia"

It has been suggested that the decreased urine content of

mended allowances of the Food and Nutrition Board of the National Research Council, the subjects remained in good health on this diet for four to almost seven months without any evidence of physical deterioration as measured by physiological responses to standard exercises as on the bicycle ergometer, with bar bells and with dumb-bells, by clinical observations and by analyses of blood and urine

Exhaustive work (6 6 to 7 7 cals per min) on the bicycle ergometer was performed twice each week at a simulated altitude of 15,000 ft and three times weekly at ground level Although the work capacity of the men on the basal diet averaged at altitude only 60% of that at ground level, increasing supplementation of the diet with thiamine and riboflavin up to 2 75 to 3 mg daily afforded no improvement.

The authors concluded that 'Thiamin or riboflavin restriction or supplementation had no apparent effect on the work output in any of the subjects"

Another interesting observation is described by the authors of this report as follows '*Training did not apparently increase the tolerance to anoxia at comparative rest* However, the observations on the height and rate of return of the pulse rate, together with the data on the work output, point definitely to an increased tolerance to anoxia during and immediately after work as the training progressed

Our observations demonstrate that a program of physical training conducted at ground level can contribute to increased efficiency for work at high altitude They suggest that such a program of training may in a measure take the place of acclimatization in *mountainous regions*"

FOOD ACCEPTANCE AT ALTITUDE

The problem of rationing aviators and troops stationed at high *altitude is not by any means determined* solely by nutritional considerations As Dove (1946) well says *"Each food must be evaluated not by what it possesses but by what it gives to the consumer,* and it gives to the consumer in gross value its per

cent value per unit weight times the weight of food accepted"

Experiments on human subjects reviewed above have shown conclusively the value of carbohydrate foods consumed prior to or during flight in raising altitude tolerance But unfortunately in actual practice the problem is not so simple Quoting from an unpublished manuscript (1946) issued by the Army Air Force entitled "Diet in relation to pilots fatigue" "Diets high in carbohydrate and very low in protein are not particularly the type that have the most appetite appeal Actual tests made in feeding Air Crews these high carbohydrate low protein menus showed very poor consumption of the high carbohydrate foods variety and quality of the high carbohydrate food items may increase their acceptability In the meantime the inclusion of high carbohydrate 'snacks' such as the Air Crew Lunch' is a step in the right direction"

The factors affecting food preferences have been discussed by Eppright (1947) and some of the characteristics of human appetite by Goetzl and Stone (1946) Approaching the latter subject experimentally, the authors observed a definite correlation of threshold values of the sense of smell one factor in appetite, with the energy content of the food consumed in all subjects and at all times meals were preceded by a period of significantly declining and followed by one of significantly rising threshold values of the sense of smell

But the pertinent problem for this section of the report is that concerned with the effect of altitude and anoxia on appetite and food acceptance The Naval Medical Research Institute (1945) has reported experiments designed to ascertain whether rats will select an optimal diet with respect to salt for the satisfaction of nutritional requirements under conditions of altitude anoxia No difference was noted between the intake of salt (or of water) at ground level and at altitude Gellhorn and Hailman (1943) in their discussion of the effect of anoxia on the sense organs cite data by Hingston (in turn cited from Barcroft) indicating a diminution of taste sensations and inability to taste onions and peppermint at an altitude of 16,500 ft Friedemann (undated) has made further citations from the experiences of Major Hingston as medical officer of the Mount Everest Expedition of 1924

The general opinion of this expedition was that sweet things were the most palatable and meat the least palatable at 19,000 ft

Green and Butts (1945) studied the factors affecting acceptability of meals served in the air by noting the relative consumption of 100 food items contained in some 10,000 meals served at altitude and compared the findings with those secured with the same served at ground level " the highest acceptability aloft is possessed by baked goods and desserts Soups, beverages, and meats show roughly equal consumption in both environments Salads, potatoes, and vegetables have air acceptability about 80% of that on the ground Breadstuffs and desserts, however, since they are palatable even when cold, often were eaten when the mission was too short to allow heating of the remainder of the meal Even so, the consumption of breads and desserts on individual long missions was equal to, or better than that observed on the ground Food is regarded much more critically in the air Minor alterations in taste, odor, and appearance considerably affect acceptability Consequently, great attention must be paid to skilled preparation, flavor, and eye appeal"

The problem of the peculiar features of menu selection for aviators is discussed by Weaver and others (1947) and by Armstrong (1943) with less obvious association with quantitative observations of food preferences in the air as contrasted with those on the ground Crocker's book (1945) on flavor, discusses the effect of serving foods hot or cold on flavor and acceptability

Published Russian experiences indicate that the fat components of the diet of aviators should be restricted (Vladimirov *et al*, 1945), and emphasize the diminution of appetite at altitude, the early loss of appetite for meat and the continuing appetite for sweets (Krotkov, 1947) A supplement of acid fruit is recommended

THE EFFECT OF DRUGS ON ALTITUDE TOLERANCE

The effect of drugs on altitude tolerance is not an integral part of the subject matter of this report, but much material (not at all exhaustive) of this description was collected incidentally in the

se of our literature coverage Since it may be of value to the lers of this book, it has been condensed in tabular form and ented on page 152 without further comment

CONCLUSIONS

he effects of altitude on animal metabolism are due predominly to a diminished partial pressure of oxygen in the inspired and in the alveolar air The anoxia thus produced may not t the basal metabolic rate appreciably, though the evidence nflicting on this point, nor the efficiency with which muscular k is done, but it clearly depresses the mental faculties, the ty of sensory impressions, the will to work, the endurance of king and the work capacity The respiratory effort required ansfer a unit of oxygen from the ambient air to the alveoli is ourse increased, and the hyper-ventilation induced will inse to some extent the evaporation of water from the respirapassages Under greatly diminished partial pressures of oxythe renal function and the motor, secretory and absorptive tions of the gastrointestinal tract may be impaired The abolism of carbohydrates is definitely disturbed, though the rimental evidence as to the direction or the extent of the disances is not unequivocal, except possibly for the induction of etacidemia

hese disturbances in body functioning induced by anoxic xia are not known to increase nutrient requirements with the sible exception of water, and here the increase would not be siderable There are suggestions that the requirements for orbic acid, for thiamine and for nicotinic acid may be inised, but there is nothing approaching a demonstration in nan nutrition

ertain dietary alterations in pre-flight and in flight meals have n shown to increase tolerance to altitude, equivalent in human jects at altitudes of 15 000 to 17,000 ft, to about 2,000 ft This rease in tolerance relates to the difference between highbohydrate and high protein meals The difference in altitude rance associated with prescribed high carbohydrate meals and

freely chosen meals is much less than this The ingestion of carbohydrates as compared with protein foods immediately before and during flight to altitude increases mental efficiency, neuromuscular coordination, the capacity for muscular work, the field of peripheral vision, and the acuity of vision in dim light It defers syncope for a longer time and decreases the severity of the symptoms of decompression sickness

Vitamin supplements to an adequate diet have not been shown to be effective in increasing tolerance to anoxia in man In particular, vitamin A supplements to an adequate diet have not been shown to increase light sensitivity in the dark adapted eye, n should such an effect be expected since the anoxic impairme in light sensitivity in dim light seems to relate to a differen mechanism than the rhodopsin cycle in which vitamin A is involved Ascorbic acid supplements and supplements of the vitamins of the B complex have not been shown to be effective antianoxic agents in man

The relation of foods to abdominal gases and abdominal gas pains at altitude is not as simple as it might seem Foods containing difficultly digestible carbohydrates that may be expected to ferment in the lower levels of the intestinal tract, should, one would presume, be avoided in pre-flight or in in flight meals but not all such foods have been shown to give trouble Blair's extensive studies show that the only consistent relation of gas discomfort to particular items of a freely chosen diet is found with carbonated water drunk prior to flight and with the consumption of melons Extreme variations in the proportions in the diet of proteins, carbohydrates and fats have revealed less gas discomfort at altitude when the carbohydrate content is kept at a low level Behnke (1941–42) believes that efforts toward the prevention of this condition should be directed toward the limitation of air swallowing, by limiting gum chewing, for example

The favorable effects of carbohydrate foods on altitude tolerance does not mean that an alteration in the day's menu is necessarily indicated The desired result can be accomplished by a shift in the usual planning of meals such that meals taken prior to flight or in flight include a high proportion of sugars and sugar-yielding foods, leaving the high protein and high fat foods largely

to post-flight meals In fact, in view of the apparent preference of men for sweet foods at high altitudes and their distaste for high protein foods, free choice meals may serve the purpose Candy snacks, preferably sugar candy, might be wisely provided for prolonged flights

It should be noted in particular that the favorable effects of carbohydrate foods on tolerance to anoxia have been observed under conditions of air breathing but at altitudes where normally pure oxygen would be provided There is some reason to believe that much of the favorable effects of carbohydrate foods would not be evident during oxygen inhalation except at very high altitudes Direct investigation of this problem is needed

The experiments on animals concerned with altitude tolerance and its modification by dietary means are often conflicting among themselves and in contrast to human experience As an example, the unanimously favorable effects of carbohydrates observed on human subjects have, as often as not, not appeared in animal experiments These discrepancies indicate either that the technic of animal experiments of this type is imperfect, or that information secured on animals is frequently inapplicable to man or both A common fault in animal experiments is to disregard and to leave uncontrolled the food intake of the experimental animals, in spite of the fact that the level of food intake, particularly when inadequate, is (and has been shown to be) an important determinant of altitude tolerance

TABLE II

Effects of Treatments Other Than Nutritional on Altitude Tolerance, Including Massive Vitamin Dosages

Treatment	*Subject or Preparation*	*Remarks*	*Reference*
Drugs			
Aminophyllin + demerol	Man	Failed to alleviate or prevent decompression sickness	Williams *et al* (1946)
Ammonium chloride	Man	Increased tolerance one to two days after ingestion	Barach *et al* (1946)
	Man	Beneficial effects of ammonium chloride + O_2 were additive	Barach *et al* (1947)
	Man	Failed to prevent mountain sickness	Barron *et al* (1937)
	Rabbit	Prevented death from aeroembolism	Catchpole and Gersh (1946)
	Man	Caused a gain of 1,000 to 2,000 m in altitude	Christensen and Smith (1936)
	Man	Better performance at altitude	Douglas *et al* (1933)
	Dog	Adaptation to conditions of low O_2 pressure took place quickly	Goebel and Marczewski (1938)
	Man	Gastric secretion of HCl uninfluenced at altitude	Hartiala and Karvonen (1946)
	Man	Work capacity at altitude improved	Hartmann and von Muralt (1934)

Ammonium chloride (cont.)	Man	Reduced incidence of incapacitating symptoms of decompression sickness in some but not all susceptible persons	Hodes and Larrabee (1946)
Amphetamine	Rabbit	Produced marked resistance to O deficiency	Ishikawa (1939)
	Man	Improved carbohydrate oxidation in anoxia	Ivy *et al* (undated report to O.Q.G.)
	Man	Increased tolerance to low barometric pressure	Margaria and Faraglia (1940)
	Man	Increased altitude tolerance indicated	Ruhl (1943)
Amphetamine or benzedrine	Man	Undesirable effects outweighed advantages gained in increased performance	Russell (1947)
Amphetamine + O	Man	Significantly decreased incidence of intolerable bends	Ivy *et al* (1943)
Amphetamine or benzedrine	Man	Eradicated intolerable bends markedly reduced incidence of bends	Ivy *et al* (1943)
	Rat	Increased resistance as indicated by the EEG in moderate anoxia	Kessler *et al* (1943)
Army Motion Sickness Remedy (Na amytal atropine sulphate and scopolamine hydrobromide)	Man	No demonstrable value in preventing swingsickness (simulating airsickness)	Smith (1946d)
	Man	Seemingly no more effective than its content of atropine and scopolamine in preventing swingsickness	Smith (1946d)

TABLE II–(*Cont d*)

Treatment	*Subject or Preparation*	*Remarks*	*Reference*
Drugs			
Aspirin	Man	Time at altitude prolonged	Burkhardt *et al* (1947)
	Man	Decreased the incidence of bends	Ivy *et al* (1943)
	Man	No significant change in incidence of decompression sickness	Thompson *et al* (1944)
Aspirin + codeine	Man	Failed to alleviate or prevent decompression sickness	Williams *et al* (1946)
Atropine Sulfate	Man	Increased the incidence and severity of pain due to intestinal gas	Blair *et al* (1947)
Atropine Sulfate	Man	Effective in preventing swingsickness	Smith and Hemingway (1946)
Benzoyloscine	Man	Moderately effective in preventing swingsickness	Smith and Hemingway (1946)
Benzoyltropine	Man	Moderately effective in preventing swingsickness	Smith and Hemingway (1946)
Caffeine	Rat	7 per cent effective in stimulating respiration following respiratory arrest at 5 280 ft	Blood and D Amour (1949)
Codeine	Man	Average time at altitude was prolonged	Burkhardt *et al* (1947)
Coramine	Rat	100 per cent effective in stimulating respiration following respiratory arrest at 5 280 ft 29 per cent effective at 40 000 ft	Blood and D Amour (1949)

Coramine and similar drugs	Man	No effect upon [illegible]	Ruhl (1943)
Demerol	Man	Average time at altitude was prolonged	Burkhardt *et al* (1947)
Demerol	Man	Negligibly effective in preventing swingsickness	Smith and Hemingway (1946)
Digitalis	Rat	Gave no relief to anoxic symptoms	Campbell (1938)
Dilantin sodium	Rat Mouse	Enabled ceiling to be raised an average of 18 mm Hg Prolonged survival of mice at 150 mm Hg	Hoff and Yahn (1944)
Dramamine	Man	Prevented or gave complete relief from motion- or seasickness	Gay and Carliner (1949 a, b)
Dramamine	Man	Prevented airsickness at 5,000 ft in 71 3 per cent of treated cases as opposed to 44 4 per cent of controls not affected	Strickland and Hahn (1949)
Hematropine	Man	Moderately effective in preventing swingsickness	Smith and Hemingway (1946)
Hyocyamine hydrobromide	Man	Effective in preventing swingsickness	Smith and Hemingway (1946)
Hyoscine-HBr	Man	Potent preventative of airsickness	Lilienthal (1945)
Hyoscine	Man	Moderately effective in preventing airsickness	Smith (1946b,c)
Methyl atropine nitrate	Man	Slightly decreased intestinal gas	Blair *et al* (1943)
8-Methyl caffeine	Man	Increased visual acuity for 60 to 80 min at low pressure and low visibility	Streltsov (1944)

TABLE II—(*Cont'd*)

Treatment	*Subject or Preparation*	*Remarks*	*Reference*
Drugs			
Methylene blue	Man	Prevented or completely alleviated symptoms of air sickness at 10 000–15 000 ft	Brooks (1948)
Methylene blue (+ O_2 breathing)	Man	O_2 saturation of blood increased	Brooks (1945)
Methylene blue	Dog	Restored altitude tolerance lost by administration of Na nitrite	Lawson (1942)
Methylene blue	Rat Mouse	Increased resistance of both animals to anoxia	Peterson (1941)
Methylene blue	Man	Showed no effect upon altitude tolerance	Ruhl (1943)
Metrazol	Rat	50 per cent effective in stimulating respiration following respiratory arrest at 5 280 ft	Blood and D'Amour (1949)
Morphine	Man	Physiologic importance still difficult to assess	Peterson *et al* (1945a)
Morphine	Man	Effective in relieving decompression pain	Smith (1946a)
Nembutal	Rabbit	Muscular immobilization produced tended to favor survival	Catchpole and Gersh (1946)
Papaverine	Man	Increased the incidence and severity of pain due to intestinal gas	Blair *et al* (1947)

Papaverine	Man	No significant changes in the incidence of decompression sickness	Thompson *et al* (1944)
Pavatrine	Man	Of doubtful value in preventing swingsickness	Smith and Hemingway (1946)
Phenacetin	Man	Time at altitude prolonged	Burkhardt *et al* (1947)
Picrotoxin	Rat	15 per cent effective in stimulating respiration following respiratory arrest at 5,280 ft	Blood and D'Amour (1949)
Potassium cyanide	Rat	50 per cent effective in stimulating respiration following respiratory arrest at 5,280 ft	Blood and D'Amour (1949)
Prostigmine Br	Man	Increased the incidence and severity of pain due to intestinal gas	Blair *et al* (1947)
Scopolamine	Man	Effective in preventing swingsickness	Smith and Hemingway (1946)
Scopolamine + chlorobutanol + benzedrine	Man	Insignificantly more effective than scopolamine in preventing swingsickness	Smith (1946d)
Scopolamine + neostigmine	Man	Less effective than scopolamine in preventing swingsickness	Smith (1946d)
Scopolamine + thiobarbiturate	Man	Did not increase effects of scopolamine in preventing swingsickness	Smith (1946d)
Sodium barbital	Man	No demonstrable value in preventing swingsickness	Smith (1946d)

TABLE II—(*Cont d*)

Treatment	*Subject or Preparation*	*Remarks*	*Reference*
Drugs			
Sodium bicarbonate (given with ammonium chloride treatment)	Man	Alleviated symptoms of acidosis produced by the chloride	Barach *et al* (1946)
Sodium bicarbonate	Rabbit	Ineffective in protection against aeroembolism	Catchpole and Gersh (1946)
	Man	Blood lactic acid lowered at high altitude invariably higher than when NH_4Cl is administered	Hartmann and von Muralt (1934)
Sodium bicarbonate	Rabbit	Animals less apt to become acclimatized to O_2 deficiency than normal or NH_4Cl treated ones	Isikawa (1939)
Sodium bicarbonate	Man	Produced alkalosis causing decreased resistance to anoxia	Margaria and Faraglia (1940)
Sodium ethylallyl thiobarbiturate (V 5)	Man	No demonstrable value in preventing swingsickness	Smith (1946d)
Strophantin	Rat	No change in tolerance to altitude	Campbell (1938)
Strychnine	Rat	71 per cent effective in stimulating respiration following respiratory arrest at 5 280 ft	Blood and D Amour (1949)
Sulfadiazine	Man	No effect upon susceptibility to swingsickness	Smith (1946d)

Sulfanilamide	Dog	Increased tolerance	Lawson (1942)
Sulfanilamide	Man	Lowered an aviator's ceiling by some 5 000 ft	Mackie (1939)
Sulfapyridine	Guinea pig	Slightly decreased tolerance to anoxemia	Grandpierre *et al* (1947)
Sulfathiazole	Man	Failed to significantly alter ability to withstand effects of altitude	Peterson *et al* (1945b)
Yohimbine	Man	No limitation of performance	Meister and Hestermann (1940)
	Man	No effects noted on ECG muscle action potentials or heart rate	Geppert *et al* (1944)
Enzymes			
Cytochrome c	Guinea pig less than 1 day old	No aid in artificial resuscitation of animals having gone through cycle of hyperpnea convulsions and slow gasping respirations	Benjamin (1948)
	Rat	Ineffective in prolonging survival time	Christiansen and Clinton (1947)
	Rat	Marked increase in liver erythrocytes and hemoglobin increased liver regeneration noted	Drabkin (1947)
	Rat	No effect on survival time to anoxia	Michel and Scheinberg (1947), Scheinberg and Michel (1947)

TABLE II—(*Cont'd*)

Treatment	*Subject or Preparation*	*Remarks*	*Reference*
Enzymes			
Cytochrome c (cont)	Rat decapitated after 8 min in 3 per cent O_2 subsequent to injection	No effect noted upon hydrolyzable phosphate in kidney and heart tissues	Miller *et al* (1948) [c f Potter (1947)]
	Rat Dog Man	Prevented decrease of tissue hydrolyzable P in rats the ECG effects of anoxia in man, and the irreversible state in hemorrhagic shock in dogs	Proger and Dekaneas (1946), Proger *et al* (1945a, b)
Adrenal and Pituitary Hormones			
Adrenaline	Heart lung preparation	Caused rapid breakdown of glycogen in anoxia	Bogue *et al* (1939)
Adrenaline	Guinea pig	Lowered tolerance to altitude of 9 500 m	Bronshtein (1944)
	Rat	Gave no relief to symptoms of anoxia	Campbell (1938)
	Rabbit	Increased anoxic hyperglycemia	Gellhorn and Packer (1939)
	Rabbit	Reduced effectiveness upon blood sugar in prolonged anoxia	Gellhorn and Packer (1940)

Adrenaline (cont)	Rat	Reduced effectiveness upon blood sugar in prolonged anoxia	Malmejac (1946) Van Middlesworth *et al* (1944)
	Chloralosed and bivagotomized dog	At pressures above 9 000 m hypertensive action of adrenaline decreased unless O_2 given then not evident until 14 000 ft attained	Hermann and Jourdan (1941)
	Nembutalized cat	No significant rise in resistance time to anoxia or in post hypoxic blood sugar values	Oster and Smith (1947)
17 Hydroxycorticosterone	Man	Produced no significant change in incidence of decompression sickness	Thompson *et al* (1944)
Adrenal cortical extract	Man	No significant change in altitude tolerance	Clinton *et al* (1946)
	Experimental animals	Decreased mortality rate at altitude	Armstrong and Heim (1938)
Adrenal cortical extract or desoxycorticosterone acetate	Small animals	No significant effect noted on work performance at altitude	Dorrance *et al* (1942)
(1) Adrenal cortical extract (2) Desoxycorticosterone acetate	Rat	(1) Survival rate greatly increased (2) (3) (4) did not increase survival rates	Thorn *et al* (1945)

TABLE II–(*Cont'd*)

Treatment	*Subject or Preparation*	*Remarks*	*Reference*
Adrenal and Pituitary Hormones			
(3) 17 Hydroxycorticosterone			
(4) 15 per cent Na succinate			
Commercial aqueous adrenal cortical extracts	Mouse	Without beneficial effect in acute hypoxia	Kottke *et al* (1948)
Cortin	Rabbit	Resistance to anoxia not increased	Gorelov (1939)
Eucortone	Rat	Gave no relief to anoxic symptoms	Campbell (1938)
Adrenocorticotropic hormone	Rat	Exercised a beneficial effect upon resistance	Li and Herring (1945)
Pituitary extract	Rat	No change in tolerance to anoxia	Campbell (1938)
Kendall's aqueous cortical extract	Dog Mouse	Increased mean hypoxic ceiling about 1 500 ft in acute hypoxia without effect on deterioration of coordination vision or hearing in dogs	Kottke *et al* (1948)
Desoxycorticosterone	Mouse	Without beneficial effect in acute hypoxia	Kottke *et al* (1948)

Thyroid Hormones and Endocrine Depressants			
Thiouracil	Rat	Increased survival, O_2 consumption decreased 30 per cent in 21 days, red cell and *white cell count* reduced	Gordon *et al* (1945)
	Rat	Increased tolerance to anoxia	Hughes and Astwood (1944)
	Mouse	No effect upon resistance	Kuznets and Streltsov (1947)
Thiourea	Mouse	Increased survival time	Gardner and Forbes (1945)
Thiourea	Rat	(1) Increased tolerance,	Gordon *et al* (1944)
(1) 0 5 per cent for from four to 30 days *or* (2) 200 mg injected five hrs prior to flight		(2) No apparent benefit	
Thyroidectomy	Rat	Increased resistance to anoxia	Herrlich *et al* (1941)
(1) Thyroidectomy, (2) Thyroidectomy + thyroxine treatment, (3) Dinitrophenol, (4) 1 per cent solution of thiourea	Rat Rat	No difference in tolerance between intact and operated fasted rats in (1), rats in (2) and (3) showed decreased resistance, rats in (4) showed marked increase in tolerance	Leblond (1944)
Thyroxine	Rat	Enhanced O_2 deficiency at 24°C	Campbell (1938)

TABLE II–(*Cont'd*)

Treatment	*Subject or Preparation*	*Remarks*	*Reference*
Miscellaneous			
Acetylcholine	Intestinal tissues of guinea pig and rabbit, cerebral tissues of cat	Indication of a correlation between acetylcholine content of tissue and resistance to anoxia	Welsh and Hyde (1944) (also, c f DeMichele and Scoz (1944))
Acetylcholine	Guinea pig	Resistance to anoxemia increased in male, no change in female	Franck *et al* (1948)
Carbon dioxide oxygen mixtures	Rat	Most effective in combination with glucose feeding	Britton and Kline (1945)
	Rabbit	Failed to prevent aeroembolism	Catchpole and Gersh (1946)
	Man	Adequate O_2 pressure maintained in lungs, blood and tissues in mild anoxia	Consolazio *et al* (1947)
	Mouse Man	Did not increase altitude ceiling in mice above that with pure O_2, did not increase cardiac output in man	Fenn (1944)
	Man	Improved general well being and capacity for work	Garasenko (1944)

Carbon dioxide oxygen mixtures (cont.)	Man	Greatly alleviated or completely offset anoxic effects	Gellhorn and Hailman (1944)
	Man	Added CO_2 permitted maximum utilization of available O_2 in anoxia	Gibbs *et al* (1943)
	Rat	Lowered minimum altitude tolerance to aeroembolism	Harris *et al* (1945)
	Man	No advantage on cerebral O_2 tension over pure O_2	Himwich *et al* (1942)
	Man	Not significantly superior to pure O_2 in alleviating intolerable bends	Ivy *et al* (1943)
Carbon dioxide + d-amphetamine	Man	Eradicated intolerable bends and markedly reduced total incidence	Ivy *et al* (1943)
Carbon dioxide	Dog	Produced respiratory depression in anoxia	Ivy *et al* (1947)
	Man	Altitude tolerance increased	Keys *et al* (1943)
	Cat	Increased altitude tolerance	Kline (1947a, b)
	Rat liver	Reduced the effect of anoxia on adrenal hepatic system	Nims *et al* (1946)
	Man	Increased tolerance to altitude indicated	Rahn and Otis (1947)
	Man	Improved tolerance to altitude	Ruhl (1943)
	Rat	Increased tolerance to 37,000 ft	Van Middlesworth (1944)

TABLE II—(*Cont'd*)

Treatment	*Subject or Preparation*	*Remarks*	*Reference*
Miscellaneous			
Citric acid	Man	Reduced somewhat the effects of anoxia	Molchanova (1941)
Glucose	Mouse	Increased mean hypoxic ceiling about 1,500 ft in acute hypoxia	Kottke *et al* (1948)
Hemoglobin	Man	Transfused group at altitude of 10,200 ft equal in performance to untreated group at sea level	Pace *et al* (1947)
Lactic acid	Rabbit	Prevented death from aeroembolism	Catchpole and Gersh (1946)
Vitamins			
Vitamin A or Carotene	Rat	No aid in combating effects of anoxia	Campbell (1938)
	Man	No effect upon visual threshold or rate of dark adaptation	Hartline (1946)
Vitamin A + other vitamins	Man	In vast majority of men having normal night vision, no improvement gained by supplementation	Rowland and Sloan (1945)
Nicotinic acid (or xanthine in doses similar to nicotinic acid)	Rat	Gave no relief to symptoms of anoxia	Campbell (1938)
Pyridoxine	Man	No demonstrable value in preventing motion sickness	Smith (1946d)

Riboflavin	Rat	Gave no relief to symptoms of anoxia	Campbell (1938)
Thiamine	Man	Gave no relief to gas pains	Blair *et al* (1943)
	Rabbit	Increased resistance to anoxia	Busing and Knauff (1942)
	Rat	Gave no relief to symptoms of anoxia	Campbell (1938)
	Man	No demonstrable value in preventing swingsickness	Smith (1946d)
Thiamine + metropine	Man	No incidence of discomfort due to intestinal gas	Blair *et al* (1943)
Vitamin C	Rat	No beneficial effect on tolerance to altitude	Campbell (1938)
	Man	If of any benefit, it was slight	Lucas (1944)
	Mouse Rat	Increased resistance to low O_2 tension	Peterson (1941)
	Man	Had no demonstrable effect on duration of consciousness either alone or given with glucose	Riesen *et al* (1946)
	Experimental animals	*Increased altitude tolerance*	Ruhl (1943)
Vitamin D	Rat	No beneficial effect on tolerance to altitude	Campbell (1938)
Vitamin E	Guinea pigs Rat	Greatly increased survival to anoxic anoxia on guinea pigs no such effect upon rats	Hove *et al* (1945)

Chapter V

PRACTICAL CONSIDERATIONS

The experimental and observational findings presented and discussed in the various sections of this book have established certain facts clearly and certain probabilities that need further exploration These facts and probabilities relate to (a) physiological effect of climatic factors, (b) effects of climatic stress on nutrient requirements, and, (c) effects of dietary modifications on tolerance to climatic stress In the following discussion, we shall consider the last two items only Basing judgment upon human experimentation and experiences only, it seems clear that climatic stress may modify greatly the body's requirements for food energy (calories), for water and for salt It is less certain, though probable, that under conditions of excessive sweating the requirements for iron and for calcium are increased, there is still less assurance that in anoxic anoxia induced by altitude the need for ascorbic acid, for thiamine, and for nicotinic acid, may be raised

On the other hand, it can be said confidently that certain dietary modifications increase man's comfort and efficiency under climatic stress, and his ability to tolerate such stress Carbohydrate and fatty foods are more beneficial than protein foods in combating the damaging effects of cold on heat balance and on the efficiency of neuromuscular and psychomotor performance, while carbohydrate foods are outstanding as compared with both fatty and protein foods in promoting tolerance to altitude, particularly

the anoxic effects, but also the symptoms of decompression sickness (aeroembolism) The favorable effect of sugar in combating the impairments of vision induced by anoxia are particularly noteworthy These impairments involve a restriction in the field of peripheral vision and the acuity of vision in dim light The effect of dietary carbohydrates is quite otherwise in alleviating abdominal gas pains at altitude These symptoms can, however, be prevented or alleviated by certain dietary precautions, not very well defined, and by minimizing air swallowing For men only moderately active, the specific dynamic action of food is a relatively small item both in withstanding heat and in resisting cold, and becomes even less significant as activity increases The "glamor nutrients," the vitamins, seem to confer no clearly marked or considerable effects on tolerance to climatic stress when consumed in amounts exceeding the demonstrated requirements in a non stress environment A possible exception to the latter statement may be thiamine under conditions of muscular work in severe heat, supplements of which may exert a favorable effect on endurance

The effect on tolerance to environmental stress of the dietary modifications mentioned above was demonstrated generally with diets (or with meals) involving considerable distortions of the usual proportions of carbohydrate protein and fat Furthermore, in order to demonstrate the effects more clearly, they were obtained under conditions of incomplete protection by usual procedures against the stress studied, i e , in the cold experiments the subjects were deliberately underclothed to induce a cold damage, or at altitudes where oxygen inhalation is ordinarily practiced, the subjects inspired ambient air to induce anoxic damage These are justifiable experimental procedures but procedures nevertheless, that modify the practical applicability of the observations secured

Where climatic factors increase the appetite for those classes of foods shown to be beneficial to tolerance, such as an increased appetite for fatty foods in a cold environment (if such an increase occurs generally), or for sweet foods at altitude, the prescription of appropriate diets for different climates in accordance with experimental findings becomes more feasible

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RECOMMENDED FUTURE INVESTIGATIONS

At various places in this report (see pages 41, 92, and 151), it has been noted that animal experimentation has furnished an unsafe guide to human responses to climatic and dietary changes and interactions Somet [illegible] ory animal fails to respond con [illegible] invariably exert a definite r [illegible] man, but more often the laboratory animal responds to a dietary change that is without appreciable effect on the human Often the results of animal experiments dealing with the same dietary and climatic factors are seemingly confusing and contradictory Possibly some of this apparent discrepancy between the results of animal and human experimentations is due to the fact that the climatic stress applied in the former experiments is often more severe, especially anoxic stress, than that applied in the latter Whatever the reasons for these discrepancies, they operate to discount the value of animal experimentation to the problem of the relationship in man of nutrition and climatic stress However, animal experimentation along these lines, when perfected, will afford valuable contributions to general and comparative physiology and to comparative nutrition Some problems within the area under discussion may, from their very nature, require animal experimentation because of the procedures that must be used or the rigors of the controls that must be exercised But for most problems of this nature, the human subject should be employed and in sufficient numbers to establish the statistical validity of any experimental effects that may be observed

To the authors, the evaluation of human dietaries, under either stress or non-stress conditions, by animal experimentation, especially by use of the ubiquitous albino rat, cannot be justified, although it is a not uncommon practice (Williams, 1947) Qualitative, but particularly quantitative, differences between rat and man in their nutritive requirements militate against the value of such appraisals except where species differences have been shown to be inconsiderable Under climatic stress the laboratory animal

generally responds so differently, in kind or degree, from the human as to render comparison difficult

It would therefore seem reasonable to recommend that the problems in the field under discussion to be noted below be studied with human subjects, and that the laboratory animal be used only in 'pilot tests Furthermore, we agree with Dill (1947) that "Laboratory investigations that concern man in his everyday life, whether at work or at war, require an accompaniment of field studies if they are to have realism and vitality"

Information on the following problems in the relationship of nutrition to climatic stress is needed

1 The quantitative effects of climatic factors on the nutritive requirements of men is almost an unexplored field of study, even the variations of energy requirements with climate and weather changes Current textbooks on nutrition, by their omission of reference to such effects or their inadequate treatment of them convey the impression that nutritive requirements are the same for all environments, with one or two notable exceptions Changes in energy requirements should modify the requirements of all those micronutrients, mineral or vitamin in nature, whose functions are concerned with the liberation of energy from the macronutrients, the carbohydrates, fats and proteins The solution of the problem whether nutritive requirements prevailing in a protected environment are modified in a stress environment has not proceeded very far

2 The effect on tolerance to intense cold of (a) diminishing the intervals between meals with meals of different character and (b) inserting snacks of different composition (sugar candy, sandwiches, etc) between the regular meals There is reason to believe that such extra meals or snacks, in proportion to their contents of carbohydrate and fat would exert a favorable effect on tolerance to cold (Mitchell *et al*, 1946), as well as contribute to an adequate caloric consumption, which is so often difficult to attain under field conditions

3 The losses of minerals in sweat and particularly the mineral balances and requirements of calcium and of iron under conditions of profuse sweating (see pages 88 and 89), need further study Before such losses can be assumed to represent increased

requirements, it must be shown that they are not associated with compensatory decreases in losses by other channels, such as kidney, or intestinal mucosa

4 The effects of carbohydrate, fat, and protein meals (or snacks) on the tolerance to anoxia under conditions of oxygen inhalation at very low pressures, equivalent to altitudes of 40,000 ft or more Are the effects of sugar supplements and of oxygen inhalation on tolerance to anoxia additive?

5 The effect of the character of the diet, the distribution of meals, and of dietary supplements between meals on the rate of acclimatization to heat and to anoxia

6 The effect of intense heat, intense cold and hypoxia at altitude on preferences for different kinds and classes of foods and for different methods of food processing and preparation The technic of such tests should be perfected with reference to their physiological aspects and their statistical interpretation (see *Henderson, Bean and Ashe, 1945, for example*)

7 The relative acuity of the senses of taste and smell under different conditions of climatic stress

8 The comparative effect on tolerance to cold, to heat and to hypoxia of those diets shown to be most favorable in these climatic situations with those rations in current use in regions where such stresses prevail or recur periodically From the military standpoint, a comparison of these experimental rations with rations which, in the experience of the OQMG, have proved to be most satisfactory in the Army

9 Fundamental physiological information concerning the effect of diet under conditions of climatic stress on those organs and systems of the body most intimately concerned with tolerance to such stress, because of their functions in regulating the heat economy, the body temperature and the transfer of oxygen from the atmosphere to the tissues These systems are the pulmonary system the cardiovascular system, the blood, and the skin, representing the main area of contact between the body and its environment The properties of the skin to hold and to release water under climatic variation, to insulate the deep tissues of the body, to protect itself against the damaging effects of direct sunlight

and to combat parasitic invasion (bacterial, fungal and insect), may possibly be influenced by diet[7]

RECOMMENDED INCLUSION IN FEEDING PRACTICES OF INFORMATION DISCUSSED IN PREVIOUS CHAPTERS

Certain facts on the interrelations between diet and climatic stress have been clearly established Whether these facts warrant modification of rations for troops, or non-military expeditions, or resident communities in different climates or subjected to different climatic stresses, is a matter involving many other considerations Any increase in the number of standard rations for Army or other use should offer distinct and considerable advantages over present rations in greater efficiency of personnel under the conditions for which they have been designed The proposed additional rations should be highly acceptable so that their consumption in adequate amounts would be assured Their packaging, transportation and preservation should be possible in a practical and satisfactory manner

The advantages of certain types of diets in certain climatic situations have been shown to be distinct, but as compared with prevailing Army rations there is no assurance, from evidence at present available, that these advantages would be considerable In the field of aviation, the engineering and technological advances in combating bends and anoxia (pressure breathing, pressurized cabins, pre flight denitrogenation, improved oxygen equipment) are so much more effective than dietary (or menu) modifications as to render the latter of little, if not insignificant, importance in most situations, combat or otherwise

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Reference might be made here to the studies of Haldi, Giddings and Wynn (1942) on the dietary control of water content of skin of Edwards and Duntley (1939) on skin pigments of Mayr (1943) on cutaneous nutrition and metabolism and their influence on the healthy and the diseased skin of Amersbach *et al* (1941) on the effect of vitamin deficiencies toxic agents and cosmetics on skin respiration of Radsma and Nizar (1938) on dermal production of lactic acid and of Burtenshaw (1942) and Cornbleet (1933) on the skin's capacity for self disinfection

It is conceivable, however, that certain critical situations may make it advisable, or even imperative, to take advantage of every available expedient to supplement engineering and technological equipment in promoting personnel efficiency. In polar or subpolar missions, appropriate dietary modifications may reduce to some extent cumbersomeness of the protective clothing that need be worn; in airplane flights at extreme altitudes appropriate preflight and in-flight meals may well contribute significantly to operational efficiency, or may reduce significantly the hazard of explosive decompression resulting from combat, when seconds of prolongation of effective consciousness may mean the difference between life and death.

In these situations all available information on the interrelations of diet and climatic stress, as well as the information to be secured from future research, should be valuable to the OQMG, for example, in discharging its functions in the Army. It may be put to good use in devising special rations (or meals) for critical situations and in the indoctrination of personnel with regard to on-duty feeding practices.

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ADDENDUM

Since the above bibliography was compiled an important series of research bulletins has appeared from the Missouri Agricultural Experiment Station under the general title *Environmental Physiology with Special Reference to Domestic Animals* by Dr Samuel Brody and his collaborators The research bulletin numbers are 423 425 433 436 449 450 and 451

Attention should also be called to a review of existing knowledge on *The Effects of Temperature Humidity Air Movement and Solar Radiation on the Behavior and Physiology of Cattle and Other Farm Animals* by Dr J D Findlay and published by The Hannah Dairy Research Institute Kirkhill Ayr, Scotland

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AND
CLIMATIC STRESS

WITH PARTICULAR REFERENCE TO MAN

By

H H MITCHELL AND MARJORIE EDMAN

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